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BATTLE DAMAGE REPAIR OF TACTICAL WEAPONS: AN ASSESSMENT

Report RE801R1



August 1989

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PREFACE

In this report we describe our findings and conclusions on the U.S. capability to repair battle damaged equipment in the Air Force, Navy, and Army. We focus on the tactical fighter aircraft in the Air Force and Navy and ground combat vehicles and helicopters in the Army. Battle Damage Assessment and Repair (BDAR) programs in each Service for research and development, advanced technology, and logistics support are critically analyzed. Finally, we make recommendations for OSD on how the Defense Department's BDAR capability can be enhanced and how OSD can better manage the overall DoD BDAR program.

Executive Summary

BATTLE DAMAGE REPAIR OF TACTICAL WEAPONS: AN ASSESSMENT

The ability to return battle damaged weapon systems quickly to combat has been a critical and sometimes decisive factor in successful military campaigns. The side that can rapidly reconstitute its forces during and after an engagement has a major advantage. Historically, the importance of repairing battle-damaged weapons has been dramatic in both long and short wars, against sophisticated or rudimentary threats. In many scenarios, the ability to repair damaged weapons is at least as important as reducing their attrition. For tactical aircraft the historical relationship is that for every aircraft lost in combat, three to five aircraft are damaged to such an extent that they must be repaired before the next sortie. While aircraft type, mission, and threat affect this ratio, analyses using combat simulations of likely future engagements show that in some scenarios (i.e., tough aircraft, close-air-support mission, unsophisticated threat), the relationship could go as high as 15:1 or 20:1. We found similar relationships for helicopters and tanks. It seems clear that in future wars we can expect large numbers of damaged weapon systems requiring repair.

Unfortunately battle damage repair does not receive much emphasis during peacetime. While each Service has a Battle Damage Assessment and Repair (BDAR) program, the programs tend to be small, underfunded, and receive less management attention than their importance warrants. Compared to programs for reliability and maintainability (R&M), and survivability, BDAR programs are severely out of balance.

BDAR IN RESEARCH AND DEVELOPMENT

Typically, research and technology efforts are small (\$100,000 – \$500,000) and do not adequately address major BDAR problems. They are viewed as "useful if affordable" rather than "essential" elements of a balanced wartime capability. Advances in repair techniques are often by-products of other research efforts. Because the BDAR research efforts are spread throughout various research areas, it

is difficult to determine the exact size of the individual programs; we estimate that each Service spends less than \$2 million annually in researching and developing new repair techniques for current and future weapon systems. Much more is needed to seriously address repair of major damage to complex weapon systems.

A more significant and systemic deficiency is that battle damage repair is not treated explicitly during weapon system design and development. At that stage of a system's life cycle the most useful improvements in repairability can be effected. Since battle damage repair is not considered in design tradeoffs, many design opportunities to improve the repairability of a weapon system are lost. Weapon systems are normally developed without regard for battle damage repair, with the expectation that the "logistics system" at a later time will somehow provide a repair capability. Some limited progress has been made. Recently, the Advanced Tactical Fighter and Light Helicopter Experimental program offices have attempted formally to incorporate BDAR considerations into their weapon requirement specifications. As a result, both programs require some analysis of the repairability of the proposed aircraft designs. In contrast to other requirements (e.g., performance, reliability, and maintainability), however, no standards or evaluation criteria are specified, and no specific design tradeoffs are required. While these first steps may raise the visibility of BDAR, it is unclear how or if they will affect the eventual design and selection of weapon systems.

LOGISTICS PLANNING FOR BDAR

Since the beginning of the Services' BDAR programs in the early 1980s, emphasis has been placed on developing a logistics structure to support a modest repair capability at the tactical unit level. All Services have adopted a general battle damage repair doctrine to repair as far forward as possible, using organic and intermediate maintenance assets — sometimes with augmentation. The Air Force plans to augment the forward maintenance units during wartime with battle damage repair teams from the CONUS Combat Logistics Support Squadrons. They have adjusted their force structure specifically to include teams dedicated to the repair of battle damage (approximately 3,000 billets organized into 11 squadrons). The Navy is considering establishing in-theater, depot-like ashore capability for repairing aircraft during war. The Army plans no additional BDAR-specific augmentation teams or units. The Air Force and, more recently, the Navy have established minimal formal initial training programs (1–2 weeks) that introduce

journeyman-level mechanics to BDAR. The Army provides very limited training on BDAR. Continuing proficiency training and/or hands-on, on-the-job training is essentially nonexistent.

For any level of expected battle damage, a significant number of damaged components and subassemblies cannot be repaired and will require replacement. Therefore, any BDAR approach requires a source of spare parts – parts that will be significantly different from those required for peacetime reliability spares. A serious deficiency now exists throughout the DoD logistics infrastructure concerning BDAR spares for two reasons: no spares are stocked for BDAR and, more important, the spares requirements systems do not treat or consider needs for BDAR spares. While the Army has taken the first step by developing an official methodology to calculate battle damage repair requirements for war reserve stocks, none of the Services now include allowances for overall battle damage repair requirements in their spare parts programs. Failure to make such allowances is a major problem because many of the parts required to repair battle damage are low- or no-failure items (e.g., structural components) and have no demand in peacetime; for that reason these parts are not currently stocked. Thus, in many cases, U.S. forces will not have essential repair spares anywhere in the supply system if they go to war. The bottom line is that logistics support for battle damage repair is inadequate.

DoD MANAGEMENT OF BDAR

Lack of DoD emphasis for BDAR can in part be attributed to a widespread misunderstanding that battle damage repair is included in ongoing major DoD initiatives. That is not so. Battle damage repair falls into "cracks" between two major DoD programs that could, but do not, cover BDAR. The large R&M program does not address battle damage repair. It focuses only on reducing reliability failures and repairing them. Likewise, the Survivability program does not address repair of battle damage. Its objectives are to reduce the number of weapon systems hit by enemy fire and of those that are hit to reduce the number attrited. Successful efforts to harden our tactical vehicles against battle damage effects will not only increase survival rates, but will also increase the number of returning damaged vehicles. Although neither the R&M nor survivability programs cover damage repair, their successes tend to increase the relative importance of having a battle damage repair capability.

RECOMMENDATIONS

We have concluded that significant additional management emphasis is required to build a BDAR program to the breadth and size that its wartime importance implies. To accomplish this, we recommend two broad actions for OSD.

First, OSD should make clear the importance of BDAR as a force multiplier and provide guidance to the Military Departments on how to include battle damage repair initiatives in their programs. Specifically, we recommend the following actions:

- Research and Advanced Technology programs should be initiated/consolidated and augmented to address directly the technical problems associated with the combat/field repair of weapon systems. Examples of high-priority areas for research are: (1) repair of composite structures; (2) repair techniques that restore low observable characteristics to damaged aircraft; (3) field repair of complex mechanical systems, such as damaged engines and power trains; and (4) field repair and/or replacement and calibration of complex electronic/electro-optical systems.
- Repair of battle damage should be made an explicit design and evaluation variable for new weapon systems. Design requirements for BDAR should be stated in system specifications (e.g., structural modularity for field replacement and access for battle damage assessment). Criteria for BDAR verification should also be specified in test and evaluation plans.
- Logistics support planning should explicitly include battle damage repair requirements. Wartime spare parts requirements computations as well as special tools, kits, and test equipment requirements should be expanded to include BDAR. National logistics support doctrine (e.g., maintenance concepts) should be reviewed to look for opportunities to use in-theater, depot-capable facilities (United States, Host Nation Support, NATO) for BDAR support.
- Initiatives should be developed to ensure adequately skilled mechanics are available for BDAR. More specialized and realistic training programs, as well as force structure adjustments (similar to the U.S. Air Force deployable small repair team organization) will likely be required to produce and maintain the highly skilled mechanics needed. Because BDAR is a wartime-only mission, the reserve components could probably meet much of this need. Also, the technical scope of BDAR training should be made more realistic by including the repair of the full range of expected damage as seen in the live-fire testing program.
- Governing policy and guidance documents (e.g., DoD program guidance, directives, and instructions for integrated logistics support and spare parts)

should be revised to explicitly include BDAR. Currently they do not directly address battle damage, although a broad interpretation of "operational effectiveness" and "suitability" could allow inclusion of BDAR. We suggest specific changes to these documents in our report. This formal and explicit recognition will help encourage the Planning, Programming and Budgeting System and Materiel Acquisition Systems to address BDAR.

Second, we recommend that management responsibility be clarified within OSD. We recommend that the Deputy Under Secretary of Defense (Tactical Warfare Programs) be designated as the OSD focal point for BDAR and that a BDAR committee be formed with representatives from the Offices of the Assistant Secretary of Defense (Production and Logistics), Deputy Director of Defense Research and Engineering (Research and Advanced Technology), and the Deputy Director of Defense Research and Engineering (Test and Evaluation) to support him in reviewing major, DoD-wide BDAR issues. Because BDAR spans the breadth of OSD activities from basic research to weapon development to buying wartime spare parts, we feel an OSD committee is required to effectively coordinate broad BDAR initiatives.

Improving BDAR should become a major priority within DoD. The emphasis on R&M and survivability over the past 20 years is paying dividends. Without commensurate progress in BDAR, however, the full benefits will not be realized when it really matters -- during combat. A commitment to improve BDAR will produce significant dividends.

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CHAPTER 1

INTRODUCTION

Over the past decade, DoD has made great strides in improving the capability of U.S. forces to generate combat aircraft sorties during wartime. We have invested heavily in reliability and survivability programs and that investment is beginning to pay off in terms of enhanced warfighting capability. Survivability considerations are now having a beneficial and growing influence on weapon systems design, selection, and tactical employment. However, we urgently need to expand the limited view of survivability — a view that focuses only on returning weapon systems *from* combat — to one that focuses on returning weapon systems *to* combat.

IMPORTANCE OF BATTLE DAMAGE ASSESSMENT AND REPAIR

The ability to return battle damaged weapon systems to combat quickly has been a critical and sometimes decisive factor in successful military campaigns. A major advantage accrues to the side that can rapidly reconstitute its forces to an operationally effective state after an engagement. Historically, the importance of repairing battle damaged weapons has been dramatic in both long and short wars, against sophisticated or rudimentary threats. In many scenarios, an improved ability to repair damaged weapons is more important than further reductions in attrition. For tactical aircraft the historical relationship is that for every aircraft lost, three to five returned with damage requiring repair before the next sortie. While that ratio depends largely on aircraft type, mission, and threat, analyses using combat simulations of likely future engagements show that in some scenarios (e.g., tough aircraft, close-air-support mission, unsophisticated threat), it can be expected to be as high as 15:1 or 20:1. (Appendix A presents information on U.S. tactical aircraft.)

Israeli Air Force (IAF) experience in the 1973 War confirms the warfighting importance of repairing battle damage. Figure 1-1 shows the detailed loss, damage, and repair results for a set of IAF aircraft. The relationship between attrited and damaged aircraft ranged from approximately 3:1 in the initial days to 7:1 later in the war. As the data show, the ability to repair battle damage was critical to the

sustained warfighting capability of this set of aircraft. Had the IAF not been able to repair the returning damaged aircraft quickly, they would have been "out of business" by Day 8. Analysis of the IAF experience with other aircraft during the 1973 War shows similar results even though the aircraft, mission profiles, and threat air defense systems encountered were different.

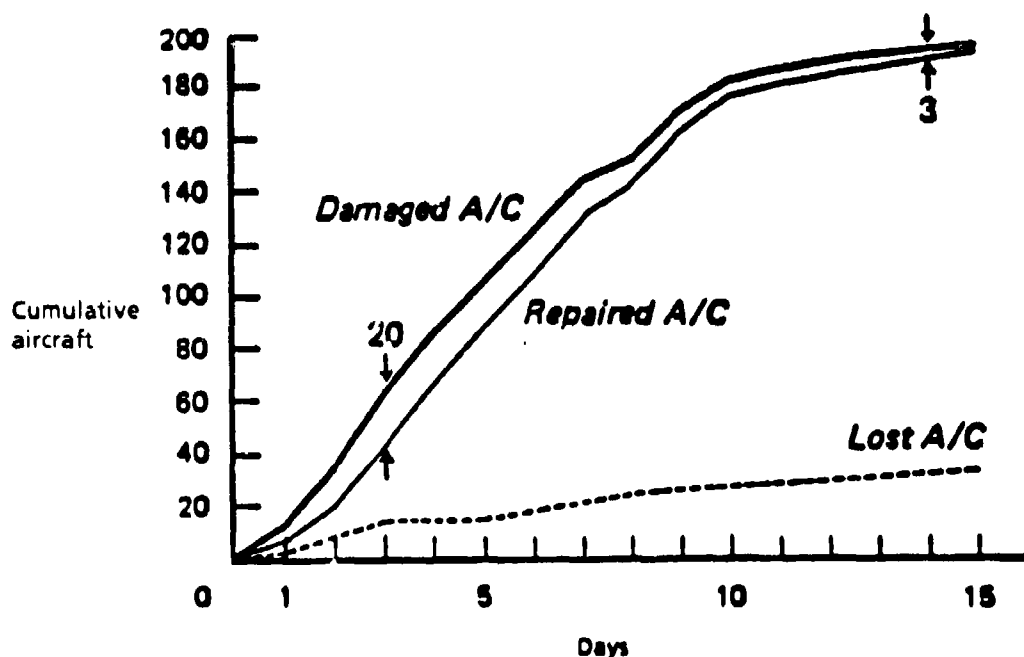


FIG. 1-1. AIRCRAFT DAMAGED AND REPAIRED

We found similar relationships for helicopters and tanks. Army studies have shown, for example, that a reasonable helicopter battle damage repair capability can increase available flying hours by 20 to 120 percent depending on the type of helicopter, mission profile, and threat encountered. The Israeli Army suffered heavy damage to its tank force in the 1973 War (75 percent of its total force) but was able to return most (80 percent) of the damaged tanks to the battle within 24 hours. The Israeli commanders credit this repair capability as turning the tide of battle, particularly in the Golan Heights. U.S. Army warfighting simulations also reflect significant numbers of damaged weapon systems, especially in the early phases of the scenarios (first 30–60 days). (Appendix B presents data on U.S. helicopters and ground systems.)

Both historical experience and modeling of future combat indicate that in future wars, we will experience large numbers of damaged weapon systems requiring repair. Unfortunately, in most weapon systems design studies, we tend to concentrate on analysis of a single sortie and not on the continuous generation of sorties over time. Therefore, we undervalue the importance of being able to repair battle damage during war. Our weapon designs tend to reflect this imbalance.

Figure 1-2 is a generalized systems description of the use of tactical aircraft during war. While many measures of merit are used to evaluate weapon systems, a very important measure is the number of aircraft over time available to fight – for the first sortie, second sortie, etc.

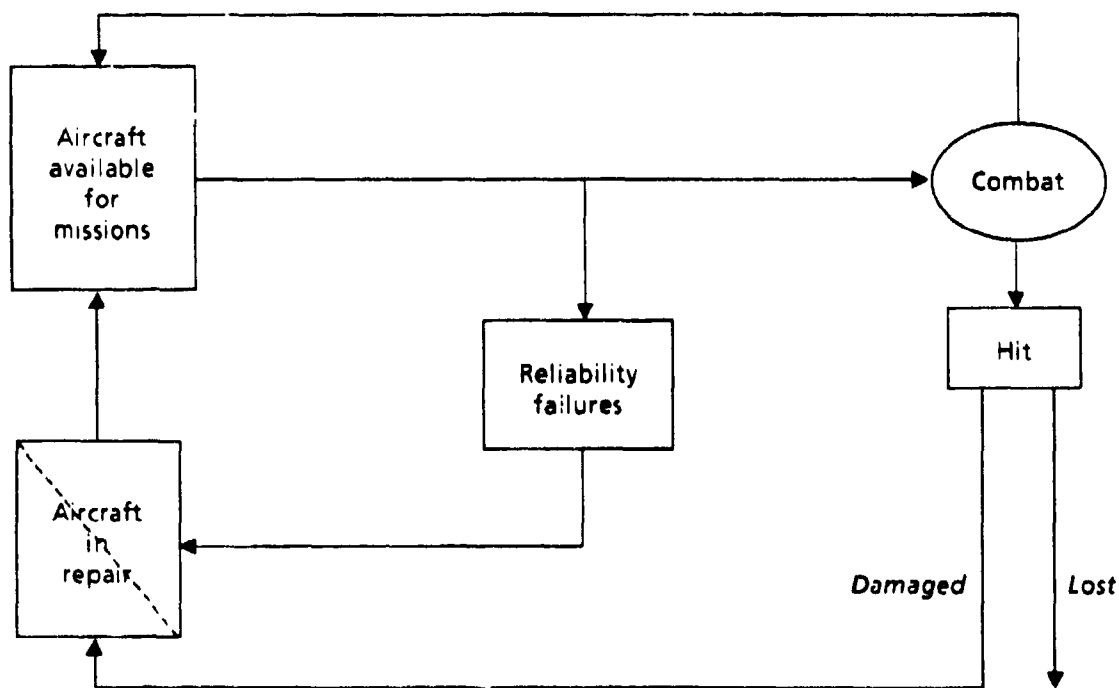
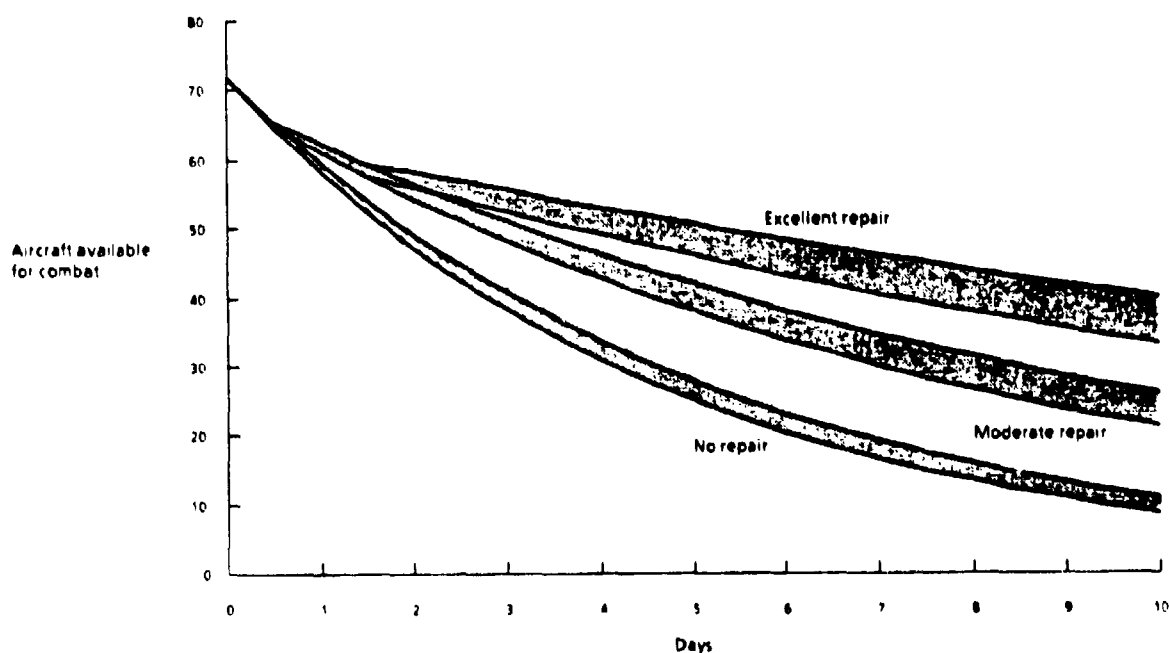


FIG. 1-2. ATTRITION, RELIABILITY AND MAINTAINABILITY (R&M), AND BATTLE DAMAGE ASSESSMENT AND REPAIR (BDAR)

The effect of battle damage on warfighting capability is dramatic. Figure 1-3 shows the results of our modeling several cases of damage repair capability using a standard scenario for a 72-aircraft wing. We analyzed various battle damage repair rates and attrition levels to determine the impact on the

number of aircraft available for subsequent missions. The battle damage repair levels considered were: (1) no repair; (2) a moderate repair capability, which is defined as reconstituting 50 percent of the damaged aircraft within 24 hours; and (3) an excellent repair capability, which is defined as reconstituting 50 percent of the damaged aircraft within 24 hours and reconstituting a total of 80 percent within 48 hours. The analysis shows that at the end of 10 days, the excellent repair capability produces approximately four times as many operational aircraft as the no-repair capability. Additionally, the analysis shows that increasing battle damage repair capability to moderate or excellent levels is much more valuable than decreasing attrition rates within the 1 to 2 percent attrition region. (The shaded areas represent the difference between 1 and 2 percent attrition at each repair level.)



Note: Attrition rate: 1 - 2 percent; battle damage rate: 8 percent.

FIG. 1-3. EFFECTIVE ATTRITION

DoD MANAGEMENT OF BDAR

Despite recognizing BDAR as a wartime force multiplier, there has been a distinct lack of emphasis within OSD on this issue. No organization within OSD has been given primary responsibility or oversight for BDAR. Consequently, little guidance has been promulgated to the Services, which is apparent in the varied

approaches, emphases, and priorities for BDAR within the Services. This lack of specific DoD-directed BDAR goals, objectives, and organization may be in part attributed to a widespread misunderstanding that BDAR is a subelement of major ongoing DoD programs such as R&M, survivability, and integrated logistics support. The fact is, it is not. It falls between the "cracks" of those programs. R&M programs concentrate only on reducing the number of random and wear-out failures and on determining the amount of resources (time, manpower, and equipment) required to repair those failures. Battle damage is not addressed by the program. Similarly, the survivability programs concentrate on returning weapon systems to friendly operating locations after a mission by reducing the number of hits and reducing the lethality of each hit. A damaged weapon that can limp back is a survivor. The survivability program does not address the requirement to return the damaged weapon to combat. A review of the applicable DoD directives and instructions reveals no BDAR language or guidance. We suggest some changes to these selected documents in Appendix C of this report. In addition, we have included in Appendix D suggested new language that will add needed BDAR emphasis within the Defense Guidance.

In the absence of specific guidance, the Services have taken disparate organizational approaches on BDAR since initiating their formal programs between 1982-1984. The Air Force has distributed responsibilities among the Air Force Systems Command (for R&D), Air Force Logistics Command (for technical orders, training aids/devices, and procurement of training assets), and the operating commands (tool kits and training courses). A central Air Force Aircraft Battle Damage Repair Program Management Office has been established to support and coordinate these efforts. The Navy has a centralized BDAR program office for tactical aircraft (OPNAV-41). The Army has primarily two major commands, the Army Materiel Command (AMC) and the Training and Doctrine Command (TRADOC), responsible for BDAR. AMC and its major subordinate commands and agencies such as Aviation Systems Command, Tank-Automotive Command, Army Materiel Systems Analysis Agency, Ballistics Research Laboratory, Materiel Readiness Support Agency, have overall responsibility for the BDAR program except for training for which TRADOC and its Logistics Center and Schools are responsible. AMC also leads the Army ad hoc BDAR program advisory group that is charged with oversight of all BDAR-related matters.

Each of the Services has adopted a very similar BDAR doctrine and policy: to repair battle damaged equipment as far forward as possible using uniformed personnel from organizational and intermediate maintenance units. The Air Force plans augmentation BDAR teams from the Combat Logistics Support Squadrons (CLSS) and the Navy will have a specially trained BDAR team on each ship with aircraft before deployment. Each Service policy provides for BDAR fixes that do not restore full operational capability to the weapon systems (i.e., degradation in performance is acceptable if approved by the commander). The Navy is also considering the establishment of in-theater, land-based BDAR depot-like repair facilities.

Because BDAR spans the breadth of OSD and Service activities from basic research to field maintenance and spare parts, we believe an organization is needed in OSD to provide BDAR guidance, program review, and coordination. That office [under the Deputy Under Secretary of Defense (Tactical Warfare Programs)] [DUSD(TWP)] would become the focal point for all BDAR initiatives and would lead a BDAR committee to oversee all aspects of the program. The committee would include, at a minimum, representatives from the Office of the Deputy Director of Defense Research and Engineering (Research and Advance Technology) [ODDR&E(R&AT)], the Office of the Assistant Secretary of Defense (Production and Logistics) [OASD(P&L)], and the Office of the Deputy Director of Defense Research and Engineering (Test and Evaluation) [ODDR&E(T&E)].

REPORT OVERVIEW

This report reviews the status of all aspects of the Service BDAR programs. Chapters 2 and 3 review and contrast the key elements of the Service programs in areas of R&D/weapons design and logistics support, respectively. Chapter 4 contains our recommendations on how the DoD can enhance the existing programs. Appendices A and B contain more detailed information on each Service's BDAR program. Appendix C provides suggested changes to DoD directives and instructions that should include appropriate BDAR guidance and direction. Appendix D contains new BDAR-directed language recommended for inclusion in the Defense Guidance.

CHAPTER 2

TREATMENT OF BDAR IN RESEARCH AND ADVANCED TECHNOLOGY, WEAPON DESIGN, AND TESTING

In general, DoD does not emphasize the treatment of BDAR in the research and engineering area. Some of the lack of emphasis may be due to a perception that BDAR is already an integral part of the R&M and Survivability programs. It is not. In fact the changes in weapon design to improve R&M or survivability may complicate battle damage repair. For example, the use of radar-absorbent material or complex shapes to reduce aircraft radar cross section will make damage repair more difficult – especially to completely restore the original low signature. Similarly, some efforts to improve reliability, such as minimizing the number of electrical connectors, result in more difficult and time-consuming damage repairs.

RESEARCH AND ADVANCED TECHNOLOGY

Research and Advanced Technology (R&AT) programs are a key to BDAR. These programs develop the techniques, materials, and support equipment that enable our forces to repair battle damaged weapons quickly in the theater of operations. The purpose of these programs is to support research to meet an identified BDAR need and to demonstrate the application of technology to BDAR. The Services' BDAR R&AT efforts began in the early 1980s and have continued at a modest funding level. For example, the Air Force Advance Development Technology Program on BDAR has been funded between \$1 million – \$2 million annually since 1985. Over the next 4 years, the Air Force program continues that level of support (Table 2-1).

TABLE 2-1

AIR FORCE BDAR RESEARCH

FY89	\$1,000,000
FY90	1,500,000
FY91	3,000,000
FY92	500,000

Similarly, the Navy BDAR R&AT efforts for tactical aircraft have been small. Until recently, the Navy has used reprogrammed funds to support BDAR research or included BDAR as a subelement in larger research efforts. Its 1989 R&AT program is \$2.2 million. The Army does not have a separate overall BDAR research program. In many instances it applies the results of other research to BDAR. We estimate the Army R&AT effort for BDAR, like those of the other Services, will be less than \$2 million annually. Because of their small size, the Service BDAR programs tend to be limited in scope and fragmented. The primary focus of these programs seems to be limited to developing rapid repair techniques for relatively light damage.

A key area of concern for all Services is the field repair of composite materials. The latest generation of weapon systems (e.g., AV-8B, F/A-18, and F-16) has incorporated these advanced materials into many areas of the structure. Designs for the next generation of weapons (V-22, Light Helicopter Experimental, and Advanced Tactical Fighter) make significantly greater use of composites, including primary structure. Composites will account for about one-half of the structural weight of these new systems. The problem is that U.S. operational forces at this time have essentially no capability to repair battle damaged composites in the field. Little is known about how to repair serious damage to composite structural components in less than depot-level facilities.

WEAPON DESIGN

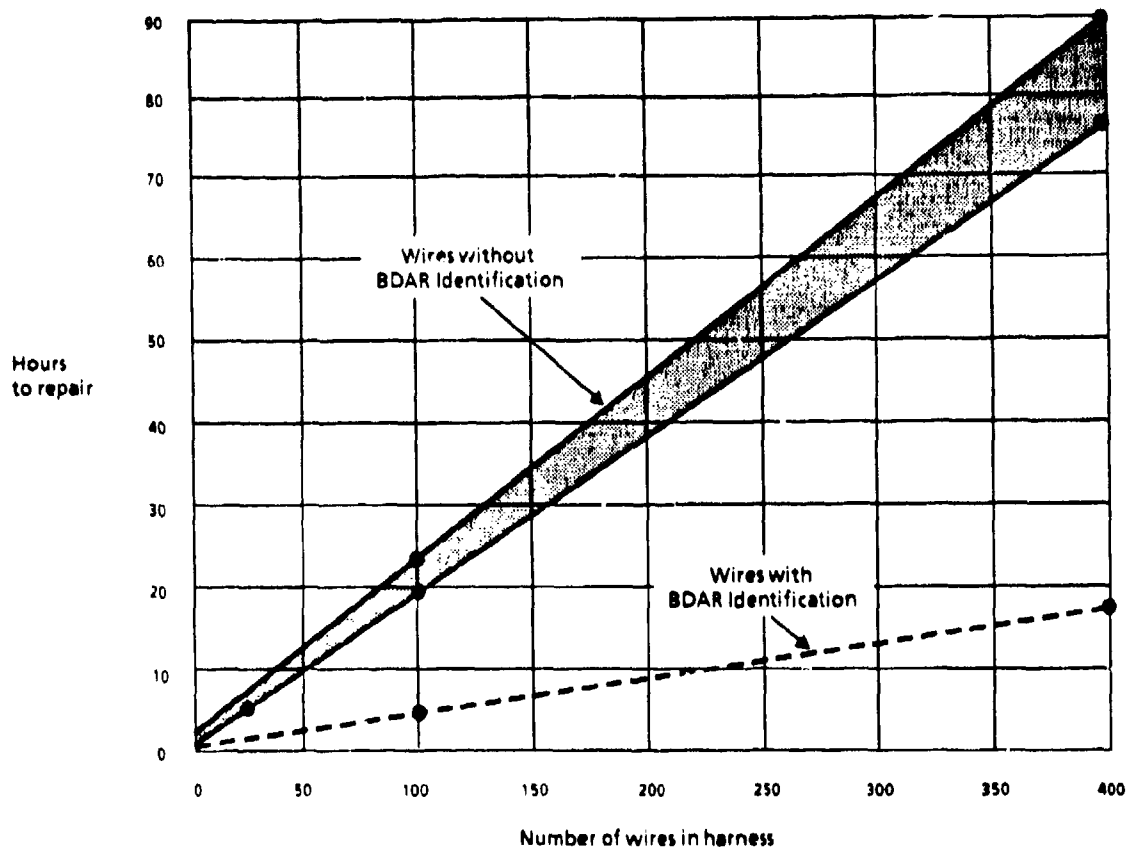
The ability to repair battle damaged weapon systems quickly is directly affected by the design of a weapon system. Decisions on materials selected, component placements, modularity for field replacement, accessibility for damage assessment, etc., determine the degree of difficulty in returning a damaged weapon to combat.

Today, the DoD weapon systems development process does not consider battle damage repairability as a tradeoff consideration during design. Several new programs (V-22, Light Helicopter Experimental, and Advanced Tactical Fighter) have requested BDAR analyses in their requests for proposals but no design standards or evaluation criteria were specified that would affect the design. This is in contrast to detailed specifications for R&M and survivability.

A classic example of the problems that can inadvertently be created by not considering battle damage repair in weapon design is the failure to mark electrical wires in many modern fighter aircraft. Sometime in the early 1970s, we stopped marking wires every few inches as had been done previously to aid in making electrical continuity checks during manufacturing, maintenance, and repair. This means, for example, that in some aircraft 30-foot cable runs of 200-wire bundles that go through several bulkheads are identified only at the end connectors. Repairing battle damage, which will inevitably occur to such wire bundles, requires extraordinarily cumbersome, time-consuming, and error-prone procedures to perform continuity checks and to identify damaged wires. Field exercises and tests demonstrate the serious difficulties caused by this simple design decision (Figure 2-1). Similarly, the Army's main battle tank has wires marked only at each end. Experience from recent live-fire tests on the M1 tank shows that we can expect most hits to result in some wire damage. The unmarked wires in the M1 are as difficult to repair as those in the aircraft. Clearly, battle damage repair was not a consideration.

TESTING

Until recently, BDAR was treated primarily as an additive excursion to weapon survivability tests. Test data from threat munitions that hit U.S. weapon systems are essential to understanding the types and severity of expected battle damage. The Live-Fire Test and Joint Live-Fire Programs, along with other Service test programs (e.g., Army exercises in Meppen, Germany), provide an opportunity to gather experimental damage data and gain repair experience on damaged weapons.



Note: ● = Empirical data based on actual repairs conducted at Ogden Air Logistics Center

FIG. 2-1. EFFECT OF WIRE IDENTIFICATION ON DAMAGE REPAIR TIME

EVALUATION

The following observations can be made about how BDAR R&D programs are being conducted by the Services. The lack of general guidance, specific goals and objectives, and reasonable resource levels have resulted in a number of deficiencies that have kept BDAR from assuming the prominence that its impact on our warfighting capability warrants. These deficiencies include the following:

- A primary focus on rapid repair of light damage
- No accepted BDAR design guidelines and standards
- No requirement to consider BDAR during the early stages of design and development of a weapon system

- No overall DoD strategy, goals, or objectives
- Limited high-level visibility and support (financial and otherwise).

The advent of advanced materials and electro-optical devices in new weapon systems creates acute repair problems in system design. While rapidly advancing technology provides the opportunity for improving weapon systems performance, at the same time, it represents a real challenge to the repair community.

CHAPTER 3

TREATMENT OF BDAR IN LOGISTICS PLANNING

Because of the importance of BDAR as a force multiplier, the logistics capability to support BDAR is essential to combat operations. The key elements in the development of an effective BDAR logistics support capability include well-thought-out repair doctrine and policies; force structure adjustments; training of skilled manpower; and adequate BDAR-specific spare parts, tools, kits, and technical documentation.

BDAR DOCTRINE/POLICY

Since the initiation of formal BDAR programs in the early 1980s, each Service has been developing a logistics program to support a modest BDAR repair capability at the tactical unit level. Although each Service has tended to emphasize and supply resources for different aspects of the BDAR logistics structure, the basic BDAR doctrine in each Service is similar, i.e., to repair battle-damaged equipment as far forward in the battle area as possible, using primarily organic unit-level and intermediate-level maintenance assets with some augmentation. In implementing this doctrine the Army views BDAR as a supplement to standard Army maintenance procedures and provides no special force structure or training additions. The Army conducts BDAR training only within standard maintenance courses (i.e., it has no special BDAR training courses). That approach is in contrast to the Air Force's and to some degree the Navy's approach, which recognize unique BDAR needs and designate specialized BDAR augmentation units and training courses.

The Service BDAR policies are by no means complete, final, and mature; policy revisions will occur over time. In fact, in the Army, TRADOC recently implemented a BDAR action plan that includes a thorough review of BDAR concepts and doctrine.

FORCE STRUCTURE

The most substantial force structure adjustment for BDAR has been the Air Force's establishment of Combat Logistics Support Squadrons (CLSS) to augment the BDAR capability of the operational combat forces. The 11 CLSS units in the force

structure — five active duty squadrons and six Air Force Reserve squadrons — have BDAR as their primary mission. Each squadron is organized into teams and is oriented to specific types of aircraft and engines. In wartime, these CONUS-based units will deploy as teams to overseas operating areas where they will be integrated into base maintenance organizations to provide additional BDAR capability. These units are maintained at a high readiness rating (C-1 or C-2).

The Army's approach to BDAR does not include BDAR-specific augmentation units. The Army force structure has maintenance teams at the battalion level and maintenance support teams at the direct support and general support intermediate maintenance level. These provide mobile maintenance assistance at the breakdown site or maintenance collection points. These teams are not specially organized or trained for BDAR.

The Navy combines both of these approaches in its force structure for BDAR. The Navy does not plan to augment its aviation units and carrier aircraft intermediate maintenance department with additional BDAR personnel, but it does plan to organize specially trained BDAR teams within the current maintenance structure. It is Navy policy that each ship with aircraft and each Marine Corps aviation squadron must have at least one trained BDAR team assigned before it can deploy. In addition, the Navy has expanded its concept to include a depot-like BDAR repair capability onshore in-theater that would be established during wartime and manned with personnel from the CONUS naval aviation depots. These organizations would be known as Damaged Aircraft Recovery and Repair Activities. No resources have been designated for this organization, however.

TRAINING

The level and extent of training for BDAR across the Services is not sufficient. Most training provides only familiarization; hands-on training is limited.

The Air Force and Navy have special formal BDAR courses that provide minimal initial BDAR training to journeyman-level mechanics (i.e., experienced maintenance personnel) and assessor training to senior noncommissioned officers (NCOs) (master skill levels). The length of this formal training varies from 5—10 days for the Air Force to 10—20 days for the Navy. The Air Force's training is decentralized at worldwide field training detachments of the Air Training Command while the Navy's training is centralized at the Naval Weapons Center at China Lake,

California. At best, this training is a basic introduction to BDAR with emphasis on generic, not weapon-system-specific, repair techniques.

The Army's BDAR training is incorporated into the standard basic and advanced NCO courses, primarily at the Ordnance Center and School, the Armor School, and the Aviation Logistics School and consists of 11–21 hours of instruction. The training is mostly familiarization training, with only limited efforts devoted to hands-on repair applications. The Army has recently instituted in its NCO courses assessor training lessons that provide additional diagnostic troubleshooting instruction.

The U.S. Air Forces in Europe (USAFE), has been the most aggressive group in providing continued BDAR proficiency training at the unit level; for example, USAFE policy requires refresher training every 6 months. Further, the periodic NATO TAC-Evaluations include BDAR events that, among other things, test the skill level of unit mechanics to perform actual BDAR during the exercise on real, nonflying aircraft (typically F-4Cs). Similar training is conducted by the CLSS. Virtually no unit-level or other continued proficiency training is conducted by the Navy or Army, nor are BDAR events currently included in training evaluations. The Army's BDAR action plan addresses the possible inclusion of BDAR training in both active component and reserve component units as well as at the National Training Center.

SPARE PARTS FOR BDAR

The DoD logistics infrastructure is seriously deficient in its ability to provide spare parts and components needed for BDAR. Any analysis of battle damage requirements shows that damage is expected to many parts that cannot be repaired. Thus, spare parts of various types and quantities will be needed to perform any serious level of BDAR. Nevertheless, Services currently do not stock spares for BDAR, and their spares requirements methodologies do not consider the need for battle-damage spares. Only the Army has an approved methodology that recognizes the need for battle-damage spares in its war reserve stocks for selected weapon systems. This problem is serious because many of the parts needed for battle damage are low- or no-failure items (e.g., structural items) that generate no demands in peacetime and, therefore, are not currently stocked.

By default, the only possible source of these parts will be through cannibalization. In sustained combat, however, a de facto, but informal cannibalization policy will not yield the increase in operational weapon systems that a reasonable sparing policy for BDAR would. Treating battle damage maintenance this way would also appear to be inconsistent with the elaborate sparing strategy in place for reliability failure maintenance. Furthermore, the Services do not train their mechanics and supervisors in efficient cannibalization techniques or management.

The Service decisions on whether to spare for BDAR are affected by their concerns for potentially increased costs, storage, and mobility requirements. The Services need to trade off the following concerns: (1) the wartime risk of not being able to return battle-damaged equipment to the fight quickly and (2) the risk of a potential decrease in peacetime operational readiness rates if BDAR spares are bought with no overall increase in costs (i.e., buy fewer peacetime spares). In this light, however, it is interesting to note that Air Force tests such as "CORONET WARRIOR" conclude that War Readiness Spares Kits, for example, stock too many reliability spares. Aircraft operational rates were sustained at higher-than-expected rates while using far fewer spares in numbers and types than predicted by the sparing models. Therefore, it may be possible to buy BDAR spares without increasing overall costs for spares and without a degradation in readiness. This subject needs more thorough research and evaluation.

TECHNICAL DOCUMENTATION

All Services now subscribe to the policy that, for future development of selected weapon systems, the contractor will be required to provide the BDAR technical manual (TM) or technical order (T.O.) as part of the integrated logistics support process. The Air Force and Army have both heavily emphasized this part of their BDAR programs. To date, the Air Force has published 8 BDAR T.O.s and the Army has published 15 TMs. Both Services have other manuals in development either in-house or under contract. The Navy published its first BDAR manual for the CH-46 helicopter recently.

These TMs and T.O.s are important for documenting known BDAR applications and for use in training. Unfortunately, they receive little use in Army field units because of the current policy against use of BDAR techniques in peacetime.

The Army is currently attempting to identify those fixes that can be approved for peacetime use and will highlight them in the TMs.

KITS AND TOOLS

The Army has developed prototype aviation BDAR kits for repair of wire, fuel pods, and fluid lines on helicopters. These self-contained kits provide the special tools and supplies needed for the repair of critical common helicopter systems. The Army is uncertain of the need for special kits for ground vehicles although some R&D effort is underway in this area. Army aviators recognize the aviation kits, especially the wire repair kit, as needed and valuable even in peacetime; but, the kits have not been procured because of funding limitations and low priorities.

The Air Force has developed BDAR kits for their aircraft maintenance units and CLSS. These kits include standard hand tools for structural, hydraulic and electrical repairs, and a limited stock of consumable items (e.g., fasteners and flexible hydraulic tubing). A kit is designed to support the basic repair needs of a BDAR team working on an aircraft. Each kit costs between \$30,000 – \$50,000 depending on the special items required by the aircraft supported. The kits are procured by the units using operations and maintenance funds. USAFE and CLSS units have been the most aggressive in procuring kits. All CLSS kits have been procured and by mid-1989 all USAFE units are expected to have their required kits (approximately 103 kits). The total Air Force requirement is 429 kits with 256 kits currently on-hand.

The Navy has not developed any BDAR-specific repair kits although some research is ongoing in this area.

EVALUATION

The Services' efforts to provide logistics support programs for BDAR fall significantly short of a balanced capability needed to support a major conventional war. The programs focus on building a modest repair capability that is oriented on repair of small, minor-damage and field-expedient, simple type of repairs. In fact, damage to aircraft, helicopters, and ground vehicles in modern warfare will be extensive and, with an increasingly more successful survivability program, even more equipment will be returning with reparable damage.

CHAPTER 4

RECOMMENDATIONS

Historical experience and combat simulations of future scenarios show that repairing battle-damaged weapon systems is critical to sustaining the combat capability of military units. The force that can quickly reconstitute after a major engagement has a decisive advantage. Even though repairing damaged weapon systems is a major part of that reconstitution process, the DoD does not have a major aggressive program in place to ensure that the treatment of BDAR is in balance with other support activities. To improve the DoD treatment of BDAR we recommend two broad actions for OSD.

First, OSD should emphasize the importance of BDAR as a force multiplier and provide guidance to the Military Departments on how to include battle damage repair initiatives in their programs. A DoD initiative on BDAR needs to span the full breadth of weapon systems development and wartime support activities from basic research through weapon design to logistic support planning. Therefore, we recommend the following specific actions:

- *Research and Advanced Technology:* We recommend ODDR&E(R&AT) initiate/consolidate and augment separately identifiable BDAR programs to directly address and resolve the technical problems associated with the combat/field repair of weapon systems. The current approach of covering BDAR as part of other research efforts does not ensure that the critical technical issues are being addressed and that the unique BDAR environment (i.e., theater of operations and intermediate maintenance level) is taken into account. Additionally, by not being part of an overall separately identifiable BDAR effort, the BDAR tasks are highly vulnerable to resource cuts. Examples of high priority research areas are:
 - ▷ *Repair of composite structures:* Currently, an extremely limited capability exists to repair composite structures in the field. Most of the research efforts in this area are focused on relatively small damage (3 – 5-inch hole) to lightly loaded areas. Live-fire test results show that much more extensive damage can be expected.
 - ▷ *Repair of low observable systems:* Research needs to be sponsored to develop repair techniques that properly integrate the signature of the repair back into the overall signature of the damaged weapon system.

This is especially critical for tactical aircraft where DoD is making large investments to reduce electronic signatures.

- ▶ *Field repair of complex mechanical systems:* Damaged engines and power trains normally require industrial-type equipment for repair. The Services' approach to field repair is to remove and replace with a scarce (limited or no stockage) and expensive subsystem.
- ▶ *Field repair and calibration of complex electronic/electro-optical systems:* Fibre-optic control systems and fire control systems.
- *Weapon systems design:* We recommend that repair of battle damage be made an explicit design and evaluation variable for new weapon systems. Design requirements for BDAR should be stated in system specifications (e.g., structural modularity for field replacement and cannibalization; and interior accessibility for assessing the type, extent, and severity of the damage). Criteria for BDAR verification should also be specified in test and evaluation plans. Additionally, we recommend DoD take immediate action to ensure that all wiring on weapon systems be marked to facilitate BDAR.
- *Logistics support planning:* We recommend that logistics support programs and initiatives for wartime explicitly include battle damage repair requirements. Currently DoD does not routinely include BDAR in logistics planning. The Israeli success in the 1973 War was due in large part to prior logistics preparations and to rapid and direct support from the United States. While each Service has a set of ongoing initiatives, we believe immediate attention should be given to the following three areas:
 - ▶ *Spare parts:* OSD should provide guidance to the Services to include battle damage repair requirements in wartime spare parts stockage calculations and subsequent spare parts procurement. As a first step, OSD should direct each Service to develop a methodology to estimate wartime battle damage spare requirements. Rather than waiting for a fully developed, optimized methodology, however, each Service should be directed to take immediate steps to identify and correct all high-payoff, highly visible deficiencies.
 - ▶ *BDAR kits and tools:* A program should be initiated to develop and procure specialized equipment needed to effectively repair the full range and extent of likely battle damage. Low Service priorities have resulted in lack of adequate funding for BDAR kits and tools.
 - ▶ *National Logistics Support Doctrine:* Services should pursue cooperative logistics arrangements for the use of allied in-theater industrial/depot-level capabilities. We expect that some weapon systems with major damage will require the use of these types of facilities that exceed U.S. intermediate maintenance capabilities.

- *Training:* We recommend that training initiatives be developed to ensure adequately skilled mechanics are available to perform BDAR. We believe this will require specialized BDAR courses that include extensive hands-on assessment and repair training. This training should encompass repair of the full range of battle damage likely to be encountered. BDAR events should be routinely included in unit exercises and evaluations which will ensure continuing proficiency training in these complex skills.
- *Force structure:* We recommend that the Army establish highly skilled, small (10-person) BDAR teams specially trained to repair battle damaged high-priority weapon systems (similar to the U.S. Air Force deployable small repair team organization). Those teams would be employed at the division and corps maintenance collection and classification points and would provide the technical engineering expertise required to assess and repair severely damaged systems. Additionally, we recommend OSD support Navy plans to establish overseas Damaged Aircraft Recovery and Repair Activities. These dedicated units will be required to produce and maintain the highly skilled mechanics needed. Because BDAR is a wartime-only mission, the reserve components could probably meet much of this need.
- *DoD policy and guidance:* We recommend that the governing policy and guidance documents (i.e., DoD program guidance, directives, and instructions) be revised to explicitly include BDAR. Currently they do not directly address battle damage although a broad interpretation of "operational effectiveness" and "suitability" could be interpreted to allow inclusion of BDAR. We suggest specific changes to these documents in Appendices C and D. This formal and explicit recognition will help encourage the Planning, Programming and Budgeting System and Materiel Acquisition Systems to address BDAR.

Second, we recommend that management responsibility be clarified within OSD. We recommend that the DUSD(TWP) be designated as the OSD focal point for BDAR and that a BDAR committee be formed with representatives from ODDR&E(R&AT), ODDR&E(T&E), and OASD(P&L) to support DUSD(TWP) in reviewing major, DoD-wide BDAR issues. Because BDAR spans the breadth of OSD activities from basic research through weapon development to buying wartime spare parts, we feel an OSD committee is required to effectively coordinate broad BDAR initiatives. Additionally, that committee can support the Conventional Systems Committee [also chaired by the DUSD(TWP)] of the Defense Acquisition Board during their review of developing weapon systems.

BDAR should become a major thrust area within DoD. The emphasis on R&M and survivability over the past 20 years is paying dividends. Unit experience with

some of the newer systems (e.g., F-16 and F/A-18) show they are achieving and sustaining unprecedented levels of high availability – a result of the DoD R&M program. Similarly, live-fire test results show that our survivability programs are producing tougher systems. Without commensurate progress in BDAR, however, their full benefits will not be realized when it really matters – during combat. A commitment to improve BDAR will produce significant dividends.

APPENDIX A

TACTICAL AIRCRAFT

SECTION 1

AIR FORCE

BACKGROUND

In the late 1970s as the results of the analyses of the Israeli Air Force performance during the 1973 War became available, the U.S. Air Force (USAF) saw the critical role that repairing battle damaged aircraft played. At that time the USAF had no formal plans, policies, or programs to support the development of an aircraft Battle Damage Assessment and Repair (BDAR) capability to be used during war. During that time (late 1970s – early 1980s) the USAF developed a BDAR concept that called for repairs to be completed as far forward as possible – at the operating location of the flying unit. It was patterned after rapid repair programs instituted by the British and Israeli forces. Early efforts focused on techniques for patching damage to "get one more flight" or turnaround in 4 hours. As the program matured, these objectives were modified and more realistic goals were developed. The focus, however, remained on field techniques (or organizational changes) to turnaround combat-damaged aircraft rapidly. Other alternatives such as establishing BDAR depot-level repair facilities in-theater or relying on CONUS depot and industrial facilities, were rejected as being too vulnerable, too expensive, or not responsive enough.

USAF BDAR POLICY

In a program management directive issued in December 1981 (updated June 1983) the Air Force established a formal BDAR policy that places the major responsibility for repairing damaged aircraft on the operating commands. In general, battle damaged aircraft are to be repaired by the aircraft maintenance units at the forward operating bases. The Air Force Logistics Command (AFLC) will support the forward maintenance units by providing BDAR augmentation – primarily skilled manpower – during war. Additionally, the policy authorizes the use of temporary repairs that do not have to restore total aircraft capability (e.g., full structural strength) or full service life (e.g., corrosion prevention).

Currently, the Air Force is in the final coordination phase of publishing a new Air Force Regulation (AFR) 66-8,¹ that sets the policies and responsibilities for the development, implementation, and maintenance of an Aircraft Battle Damage Repair capability and program to increase aircraft availability and sortie rates in a combat environment. AFR 66-8 supports the BDAR program's purpose — to enhance the wartime repair capability of aircraft maintenance activities. The program will provide procedures for developing special training, tool and material kits, evaluation criteria, advanced design technology, and the repair techniques necessary to maintain an effective BDAR capability.

WEAPONS DEVELOPMENT

Research and Advanced Technology

The Air Force BDAR Research and Advanced Technology program will be conducted under the guidelines of the about-to-be published AFR 66-8, *Aircraft Battle Damage Repair*. Under AFR 66-8, the USAF BDAR Program Management Office responsibilities are delegated to Headquarters AFLC, which provides support and guidance to the BDAR Advanced Development Technology Program (ADTP) Office, Wright Research Development Center, for R&D to achieve USAF BDAR program objectives. The overall ADTP objective is to provide validated techniques and procedures to return battle damaged aircraft to combat.

According to AFR 66-8, the Air Force intends to support R&D in new composite technology, repair techniques, and design guidance for new aircraft. Specifically, AFR 66-8 states that engineering reviews are to be conducted at each critical point in the acquisition life cycle. These reviews are to ensure potential BDAR problems associated with the system are identified and that technology data required to develop weapon systems design options for meeting BDAR requirements and criteria are developed. These data will include BDAR techniques, assessment and repair factors, and analytical techniques and methods for quantifying required BDAR resources.

Since 1980, the ADTP has been involved in some battle damage repair efforts. Initially, battle damage repair data from the Southeast Asia and Israeli War

¹AFR 66-8 was delivered to the Air Force Printing Office in March 1989; however, printing and final distribution may take as long as 1 year.

experiences were collected and analyzed, reference documentation and data were collected and cataloged, and a BDAR reference library was established. A simulator was developed and is being used currently for BDAR field training purposes. Until recently, these efforts were sponsored by the Joint Technical Coordinating Group for Aircraft Survivability at a very low level (on the order of \$800,000/year).

The Air Force BDAR R&D program is currently funded at \$6 million for FY89 through FY92. The funding breakout is shown in Table A-1:

TABLE A-1
AIR FORCE R&D PROGRAM FUNDING

FY89	\$1,000,000
FY90	1,500,000
FY91	3,000,000
FY92	500,000

The following projects are currently being pursued under this program:

- *Fuel Tank Repair Program:* investigating the rapid repair of integral fuel tanks
- *Wiring Damage Assessment Aid:* developing a computer aid device that assists the user in pinpointing wiring damage and gives pertinent information about the damage to enhance troubleshooting
- *Structural Damage Repair:* examining the capability to repair damage to large structural components made of composite materials
- *Inspection Device for Inaccessible Areas:* looking at a bore scope type instrument or device to examine damage in difficult access areas on weapon systems and component parts.

The ADTP program is also providing the BDAR Program Management Office technical support and assistance for determining the requirements for the development of a BDAR hands-on trainer and an interactive video package for BDAR refresher training.

Other Air Force BDAR research efforts are being conducted on composite supportability enhancements. Because composites require higher temperatures for

repair work, developmental research is being conducted on an induction heater type device, advanced heating techniques, and portable heater/heating blankets for field repair use. Additionally, other research on advanced materials (i.e., thermoplastics, composites, and metals), innovative aircraft structural designs and advanced repair technologies have some positive spillover effect on BDAR supportability. Advanced research on thermoplastics will address large damaged areas and multiple contour structures. Many of these repair technologies are being demonstrated during live-fire testing. The Air Force is investigating the standardization of BDAR repair tools, equipment (e.g., induction heaters), and repair techniques that will further enhance BDAR supportability.

Design

In the area of design, AFR 66-8 directs that BDAR requirements be considered in the conceptual phase of new weapon systems, refined as the acquisition cycle progresses, and cited in contracts requiring contractors to incorporate BDAR requirements in their designs and plans. Additionally, BDAR will be addressed in the Statements of Operational Need or Justification for Major System New Start. It suggests that these concept documents discuss the capability required or the impact on operations if no capability is developed, the intent being to ensure the design of the system does not overlook those characteristics that would contribute to rapid repair of combat damage. It also suggests that BDAR be considered in developing requirements and tradeoffs leading to the basic design of an Air Force weapon system. However, the regulation states that design features to enhance BDAR should not adversely impact stated performance goals, but will not be ignored in favor of performance goals alone. How will BDAR stand up in the tradeoff versus performance? AFR 66-8 is an excellent first step at ensuring that BDAR will be adequately addressed. How it will be implemented and the degree of emphasis (funding) it receives remain to be seen.

The Air Force has included BDAR in the Advanced Tactical Fighter (ATF) program. ATF program specifications require that *some* BDAR capability be demonstrated. The ATF's Statement of Work (SOW), Request for Proposal, and Integrated Logistics Support Plan also include BDAR considerations. These considerations, however, are very broad in scope and general in nature. As an example, the ATF SOW states "The ATF Weapon System shall sustain high sortie rates during long period[s] of combat." While this is an implied statement of the need

for a BDAR capability, the words are sufficiently vague and lacking specific guidance that it will be difficult for the contractor to respond effectively if any response is made. In another example, the SOW has a requirement for the contractor to "assess combat damage repair for the ATF system operating in a conventional and/or C/B warfare environment." These type statements offer only general guidance to the bidding contractor who must then quantify the requirement. Clear, specific BDAR requirements, procedural guidance on how to get there, and unqualified emphasis on the importance of BDAR to the weapon systems needs to stand out in the acquisition and contractual documentation associated with new or follow-on weapon systems.

Testing

Testing BDAR characteristics and techniques has been confined mostly to the laboratory. The Air Force participates in the Joint Live-Fire Program that is investigating the vulnerability of our current fleet of aircraft (e.g., F-16, F-15, and F-4) to battle damage. Although the emphasis in that program is placed on vulnerability testing, the program provides the opportunity to assess the battle damage suffered during the tests and tryout various BDAR repair techniques. During these tests BDAR-trained personnel from operating units [Pacific Air Forces; U.S. Air Forces in Europe (USAFE); Combat Logistics Support Squadrons (CLSS)] repair test specimens using established BDAR techniques and procedures. This has served as an excellent training tool.

FORCE STRUCTURE

To augment the BDAR capability of the operational combat forces, the AFLC established the Combat Logistics Support Squadrons (CLSS) with BDAR as their primary mission. Today, the Air Force force structure has 11 CLSSs -- five active duty squadrons and six Air Force Reserve squadrons. Each squadron is organized into teams and is oriented on specific types of aircraft and engines (Table A-2). In peacetime, all squadrons are stationed in CONUS at the Air Logistics Center that has primary responsibility for the aircraft on which they are trained. During wartime, the CLSSs will be deployed as teams from CONUS to the operating locations of the combat forces.

An example of the composition of a typical BDAR team is shown in Table A-3. Each team is made up of senior technical specialists (journeyman and master skill levels) that have had training on BDAR techniques for the aircraft to be supported.

TABLE A-2
CLSS BDAR TEAMS

Type	Team size	Number of teams	Total number of personnel
F-15 (18 PAA)	23	1	23
F-15 (24 PAA)	31	6	186
F-15 (Engine)	2	7	14
F-16 (24 PAA)	31	8	248
F-16 (Engine)	2	8	16
F-4 (18 PAA)	21	6	126
F-4 (24 PAA)	29	10	290
F-4 (Engine)	2	16	32
A-10 (18 PAA)	21	11	231
A-10 (Engine)	2	11	22
A-7 (18 PAA)	21	2	42
F-111 (18 PAA)	24	3	72
F-111 (24 PAA)	31	3	93
F-111 (Engine)	2	6	12
C-130 (16 PAA)	17	11	187
C-130 (Engine)	2	11	22
C-141 (APOD)	14	2	28
C-141 (Engine)	2	2	4
C-5 (APOD)	14	6	84
C-5 (Engine)	2	6	12
B-52 (14 PAA)	19	4	76
B-52 (Engine)	2	4	8
KC-135 (20 PAA)	18	5	90
KC-135 (Engine)	2	5	10
Engine repair	2	24	48
Aero engineers	1	78	78
Supply and packing	Ranges from 4 to 29	107	620

Under current plans, the teams will deploy along with a two-man engine repair team and an aeronautical engineer to an operating base in the combat theater. At the operating base, the teams will integrate into the base maintenance organization to provide additional skill and labor hours for battle damage repair.

TABLE A-3
A-10 BATTLE DAMAGE REPAIR TEAM

Air Force Specialty Code	Title	Number
32551	Avionics Instruments Specialist	1
42350	Aircraft Electrical Systems Specialist	1
42352	Aircrew Egress Systems Mechanic	1
42353	Aircraft Fuel Systems Mechanic	2
42354	Aircraft Pneudraulic Systems Mechanic	1
42750	Machinist	1
42755	Airframe Repair Specialist	7
42775	Airframe Repair Technician	1
43151	Tactical Aircraft Maintenance Specialist	3
43171	Tactical Aircraft Maintenance Technician	2
43200	Aircraft Maintenance Manager	1

The reported readiness of the CLSSs is very high. All units are rated combat ready (C-1 or C-2). Because the Air Force classifies equipment as a nonrated area for CLSS, these readiness ratings reflect only manpower and training status of the units. In general the active duty CLSS are rated very high while some reserve CLSS have experienced some minor personnel and training problems. Over the past year improvements have been made, and now all reserve units are rated C-2 or higher.

TRAINING

The Air Force is now training aircraft mechanics on the basic repair techniques associated with BDAR. The strategy is to train experienced journeymen and masters (5 and 7 skill levels) that are assigned to operational units. The formal classroom training is provided by the Field Training Detachments (FTDs) of the Air Training Command at bases around the world (Table A-4). Because only experienced

mechanics are trained in BDAR, the Army Training Command does not include BDAR training in basic skill training curriculum. Typically, BDAR technicians attend a 5-day training course at one of the FTDs. BDAR assessors attend a 3–5-day course in addition to the basic technician course. This training should be considered a basic introduction to general battle damage repair techniques. Generally, the training is generic to all aircraft and is not weapon-system-specific. Additionally, the Air Force Institute of Technology provides an 80-hour BDAR course to Engineering Officers. Those officers will deploy with the CLSS teams to provide on-site technical engineering support to the BDAR teams.

TABLE A-4
TRAINING SITES

Commands	Number of locations
Air Force Logistics Command	5
Military Airlift Command, Strategic Air Command, and Air National Guard	1
U.S. Air Forces in Europe	9
Pacific Air Forces	3
Alaskan Air Command	1
Tactical Air Command	14

To provide hands-on training, the Air Force has dedicated some nonflying aircraft to support BDAR (Table A-5). While many of the older aircraft are primarily structural hulks, the newer aircraft (i.e., F-4Cs) are fully equipped with a complete array of systems onboard. These planes are damaged and then repaired by the unit BDAR teams.

To date, USAFE and the CLSSs have been the most aggressive commands in training unit BDAR repairmen. Both commands have continually provided training since 1980.

TABLE A-5
TRAINING AIRCRAFT

Aircraft type	Number	Aircraft type	Number
F-4	61	C-130	2
F-105	36	C-140	2
F-101	31	B-52	5
F-111	1	707	1
F-102	1	T-33	1

LOGISTICS SUPPORT

Spare Parts

Requirements for spares to repair battle damage are not included in the overall aircraft spare parts requirements computation. All spares requirements calculations are based on either expected/demonstrated reliabilities of components or wear-out criteria and planned wartime operational tempo. Today, battle damage does not affect War Readiness Spares Kits (WRSK), Base Level Self-Sufficiency Spares, or War Reserve requirements. Therefore, the Air Force does not stock additional spares that would be needed to support BDAR.²

The potential seriousness of not stocking battle damage spare parts was investigated by AFLC in 1988.³ A combination of an aircraft damage simulation model, an aircraft damage repair model, and a theater air campaign simulation model was used to estimate combat battle damage spare parts requirements for F-4s. This estimate was compared to the current WRSK to assess the wartime sortie impact of not stocking BDAR spares. The study found that if the WRSK does not

²An exception are the spares stocks for the A-10 aircraft. The Air Force has assembled three Battle Damage Additive Spares Kits for the A-10 – one kit each in Europe, Pacific, and CONUS. Each kit has approximately enough major structural components for seven aircraft, e.g., wings. The kits would be used to support A-10 BDAR throughout the entire theater. However, the contents of the kits are not based on a rigorous assessment of the expected battle damage and the planned repair, but rather seem to be extra components purchased by the Air Force at the conclusion of the A-10 production program.

³Air Force Logistics Command-Materiel Analysis. *Computing Combat Battle Damage Spares Kits*. Jan 1988.

include battle damage spares, the entire squadron of aircraft would be grounded early in the conflict. It also found that the depth of stocks of items in the WRSK needed to be significantly increased and the breadth of stocks needed to be significantly expanded to include parts not currently covered. Given the obstacles encountered by the team (e.g., inability to completely translate the Work Unit Codes output from the aircraft damage into national stock numbers), we think the study results underestimate the seriousness of the problem.

In order to better understand the full requirement for BDAR spares, the Air Force has started a project to develop an analytical tool to estimate BDAR spares — the Requirements Quantification Methodology effort. This effort will attempt to link current combat, damage, and repair models to the traditional spare parts optimization models.

Technical Documentation

Aside from training, the USAF has placed most of its BDAR emphasis on developing BDAR Technical Orders (T.O.s) for each aircraft type. The Air Force has fielded 8 T.O.s and has 11 T.O.s under development (Table A-6). These documents contain the technical data to guide the mechanic in assessing the severity of the damage and selecting a repair technique. The focus of the BDAR T.O. program to date has been on aircraft already in the unit. The Air Force will eventually commit \$50 million — \$60 million to this program. For future aircraft, Air Force policy is that BDAR T.O.s will be required as part of the normal contractor-delivered technical data package and will be available at initial operating capability.

OBSERVATIONS

The Air Force BDAR program is becoming increasingly active. T.O.s on BDAR techniques are being published, personnel are being trained in formal training schools, CLSS units have been formed, visibility at higher levels is occurring (i.e., AFR 66-8), and limited R&D is ongoing. However, more emphasis is needed in the design and acquisition phases of weapon systems development.

TABLE A-6

BDAR TECHNICAL ORDER

Aircraft	Publication date
General BDAR	March 1980 (revised April 1984)
F-5	March 1981
F-4	April 1981
OV-10	November 1981
A-7	November 1983
F-111	November 1984
F-16 A/B	May 1986
A-10	December 1987
B-52	February 1989
C-5	April 1989
F-15A	January 1989
KC135	August 1989
F-16 C/D	May 1990
C-130	September 1990
B-1	August 1991
C-141	August 1991
C-17	August 1991
H-53 ^a	April 1990
H-60 ^b	April 1990

^a Joint development with Navy.

^b Joint development with Army

SECTION 2

NAVY

BACKGROUND

In the early 1980s, the Navy began to consider seriously the affect of aircraft battle damage on its ability to perform its mission. Again the experience of the Israeli Air Force in 1973 and the more recent British experience in the Falkland Islands convinced the Navy that it should expect and be prepared for large numbers of returning aircraft to be damaged. Navy analyses show that the ratio between the expected number of aircraft returning with damage and the expected number of aircraft attrited for Navy/Marine Corps operations ranges from 3-6:1 - generally the same as the Air Force results.

The overall objective of the Navy BDAR program is to maximize aircraft availability and sortie generation. Its goal is to have a capability for 80 percent repairability of battle damage on the carrier and the remainder at depot level. The Navy aircraft BDAR program is managed by the Aircraft Battle Damage Repair Program Office within the Naval Air Systems Command.

BDAR POLICY

In the mid-1980s, Navy thinking began to converge on an overall concept of repairing battle damaged aircraft. In general, the Navy decided to repair the aircraft in the theater of operations as far forward as possible - the Aviation Squadron Maintenance Department and the Aircraft Intermediate Maintenance Department (AIMD) aboard the carrier. Later the Navy expanded its BDAR concept to include a depot-like repair capability onshore, in-theater that would be established during wartime - Damaged Aircraft Recovery and Repair Activity (DARRA).

FORCE STRUCTURE

Because of the space limitations aboard ship and the problems associated with moving personnel and equipment from ship to ship or shore to ship, the Navy does not plan to augment the aviation units and carrier AIMDs with additional personnel for

BDAR. Instead the concept is to organize special BDAR teams within the current maintenance structure and provide these teams with additional training on BDAR. The composition of a typical Navy BDAR team is shown in Table A-7.

TABLE A-7
NAVY BDAR TEAM

Rating	Title	Number
AMS (senior)	Aviation Structural Mechanic S (Structures)	1
AT	Aviation Electronics Technician	1
AD	Aviation Machinist's Mate	2
AMS	Aviation Structural Mechanic S (Structures)	3
AMH	Aviation Structural Mechanic H (Hydraulics)	1
AT	Aviation Electronics Technician	1
AE	Aviation Electronics Mate	1

The DARRAs will be a wartime-only activity and will be manned with skilled active Navy personnel, Selected Naval Reservists, and civilian artisans from the Naval Aviation Depots in CONUS. The early design of the DARRA consists of a 23-van complex that is deployed into theater at a preselected site — similar in concept to the P-3 forward support facility. Initial planning calls for four DARRAs — two in the Atlantic theater and two in the Pacific theater. Currently, DARRAs are only a concept — no commitment of resources has been made to develop them.

RESEARCH AND ADVANCED TECHNOLOGY

Primary research and advanced technology on aircraft battle damage repair is conducted by the Naval Air Development Center (NADC), Warminster, Pennsylvania, and the Naval Weapons Center (NWC), China Lake, California.

Because the Navy has operational aircraft (F-14, F-18, F-4, and AV-8B) that have a significant number of composite material components, the Navy has been conducting research on the repair of composite material for about 10 years. In 1985 the Navy increased its emphasis on attaining a real BDAR capability and for FY89 has funded \$2.2 million of operations and maintenance funds, Navy (O&MN), for the program. Currently, NADC is conducting in-house research on composite

materials repair to include investigating hot area (i.e., IR suppressor/engine area) bolted versus bonded repair concepts, researching different types of rapidly processable composites, and developing bolted repair procedures for large (greater than 10 inches) hole structural damage repair. Additionally, NADC is evaluating the use of thermoplastic materials and innovative processing techniques to repair small (2 inch or less) damaged graphite/epoxy aircraft structures. This effort involves the application of newly emerging graphite-reinforced thermoplastic laminating materials and thermoplastic adhesives to repair graphite/epoxy aircraft components. It also involves screen-heating techniques using induction heaters for use in applying thermoplastic materials to thermoset advanced composite structures. The NADC is also investigating developing repair concepts for new aircraft designs such as the V-22. Some identified areas of concern are narrow wing stringers, filament wound composite components, bismaleimide nacelle panels, rivet-bonded flaperon, high strain wing cover, fuselage frame and post-buckled skin, and rotor blade leading edge.

NADC is focused on continuing a composite material R&D program emphasizing repair concept and technique development and validation procedures that can serve as the foundation for developing the necessary repair technical orders/manuals and training program. The Navy has developed and published a generic BDAR manual, and is developing a Navy Training Plan (NTP/OPR PMA 205).

DESIGN

For the first time, BDAR is being considered during the development of an aircraft in the V-22 program. Although BDAR was initially written out of the V-22 full scale development contract, NADC identified more than 20 V-22 unique candidate areas (e.g., the high strain wing cover and the rotor blade leading edge) for BDAR considerations. They issued a sole-source solicitation for \$5.4 million over 3 years to the prime contractor Bell-Boeing to investigate BDAR in those identified areas. A NADC area of particular concern is the degree of interchangeability of composite component parts on the V-22 aircraft which has a large percentage of composite structure. This interchangeability of component parts is particularly critical for battle damage repair where cannibalization could be a major source of replacement structural components. A specific example of this problem is the individual hand drilling of holes in a component part (e.g., an engine cowling). As a

result of the failure to invest in automatic equipment to drill the holes, precision and standardization is lost and interchanging that particular part between identical aircraft will most likely not be possible (i.e., the holes may not align correctly). This problem will certainly impact the time to repair damage and severely hamper the potential to cannibalize to obtain needed parts.

The repair of battle damaged composites create a unique set of problems in aircraft design that need immediate emphasis. With advanced technology and development of new weapon systems keyed to improved performance, capability, and sustainability, the use of composite, thermoplastic and other light, durable materials dictates the absolute requirement for a strong BDAR program during system development. The new A-12 aircraft (replacement for the A-6) presents an opportunity for BDAR requirements to be included in the early design tradeoffs.

TESTING

The Navy conducts live-fire testing on vulnerability of aircraft-composite component parts at its China Lake, California facility in conjunction with the NADC. Under the congressionally required Live Fire Test Program, all newly acquired weapon systems (any manned weapon system subjected to combat) must undergo realistic vulnerability testing to real live fire. BDAR is being incorporated into the program.

TRAINING

In the mid-1980s the Navy adopted a policy that deploying aviation units should be accompanied by trained BDAR teams. Since January 1987, each ship with aircraft and each U.S. Marine Corps aviation squadron must have at least one trained BDAR team before it can deploy. Like the Air Force, the Navy training strategy is to provide additional training on BDAR to experienced maintenance personnel. Typical BDAR technicians are E-5s on at least their second tour (journeyman-skill level). These technicians receive 10 days of special BDAR training. This training covers repair of primary and secondary metal structures, low and high pressure hydraulics, and electrical wiring. BDAR assessors tend to be E-7s and above (master-skill levels). Assessors receive 10 days of BDAR damage assessment training in addition to the 10 days of repair technician training. Unlike the Air Force, the Navy has centralized all of the BDAR training at the NWC at China Lake, California. Training started there in August 1985. The Navy has

approximately 650 trained BDAR technicians and assessors. The training represents a general introduction to BDAR with hands-on practical experiences on the fundamental repair techniques (e.g., wire splicing and aluminum skin patching). Because the Navy has not developed BDAR TMs for its aircraft, the repair techniques and procedures are generic and not aircraft specific.

LOGISTICS SUPPORT

Spare Parts

Requirements for spare parts needed to repair battle damage are not included in the aircraft spare parts computations. All spares requirements are based on usage rates, which in turn are based on either expected reliabilities of components (derived from engineering estimates or historical experience) or wear-out criteria. These usage rates are adjusted to reflect the tempo of planned wartime operations. Today, the additional and unique demands for spare parts to support BDAR are not covered by any spare stocks — Aviation Consolidated Allowance List or War Reserve. The Navy recognized this deficiency and has a limited effort underway to develop a methodology to estimate BDAR spares requirements. In this effort the NWC will build estimates of damage through an analysis of the results from live-fire testing and aircraft vulnerability models. From these damage estimates NADC will attempt to develop an estimate of the parts requirements. This effort is still in a very early stage of development.

Technical Documentation

The program to develop BDAR diagnostic and repair publications for Navy aircraft is very small. To date only one aircraft TM has been published — CH-46. The Navy BDAR Program Office planned to start the development of manuals for front-line aircraft, but has not received funding support for this effort. An example of the cost for developing these manuals is that an early estimate for the AV-8B manual was approximately \$6.5 million which is similar to the cost experienced by the Air Force. In 1987 the Navy established the following priorities for developing manuals (Table A-8). New aircraft are required to have BDAR TMs developed as part of the integrated logistics support package.

TABLE A-8
BDAR PRIORITIES

Priority	Aircraft
1	A-6
2	F-14
3	F/A-18
4	H-53
5	H-1
6	H-46
7	AV-8B
8	OV-10
9	EA-6B
10	KC-130
11	E-2
12	H-60
13	P-3
14	S-3

OBSERVATIONS

The Navy has concentrated its limited aircraft BDAR program on establishing a training program. Today, deploying Navy and Marine Corps aviation units have at least some repair personnel with a basic introduction to BDAR. In other areas progress has been much slower because of a lack of funding resources.

APPENDIX B

HELICOPTERS AND GROUND VEHICLES

HELICOPTERS AND GROUND VEHICLES

This appendix provides the background and current status of the U.S. Army's Battlefield Damage Assessment and Repair (BDAR) program including doctrine and policy, weapons development, research and advanced technology, and logistics support planning. The U.S. Marine Corps (USMC) has no BDAR program for ground vehicles and plans to rely on cannibalization and the ingenuity of its crews and mechanics to do field fixes. For its aviation assets, the USMC BDAR program is analogous to the U.S. Navy's battle damage repair program (see Appendix A - Tactical Aircraft). It should be noted that this program is an ongoing effort; therefore, this report reflects a snapshot of the status of Army BDAR efforts as of early 1989. Specific details of the program will change over time.

BACKGROUND

The Army initiated a BDAR program in 1982. By direction of Headquarters, Department of the Army (HQDA), the Army Materiel Command (AMC) was designated the lead agency. Within AMC, the Deputy Chief of Staff for Supply, Maintenance, and Transportation (DCSSMT) has oversight of this program. In order to provide guidance and monitor progress of BDAR efforts, AMC formed the BDAR Program Advisory Group (PAG), which has met 16 times over the last 5 years, with the last meeting on 18 October 1988. The PAG is comprised of representatives from AMC headquarters; AMC major commodity commands and agencies; Headquarters, Training and Doctrine Command (HQTRADOC); Army Logistics Center at Ft. Lee, Virginia; several Army schools; and Army major commands (see Table B-1 for complete listing of participants).

The BDAR PAG is organized with a chairman and two co-chairmen (one for Development and one for Requirements), with each organization providing one or more participants to the general meetings of the PAG. In the past 2 years, as the number of participants have grown, this format has changed slightly. The current PAG organizational plan is to address specific BDAR issues by forming working groups with a designated lead agency. The PAG chairman and co-chairmen meet with a small advisory group to review the progress of all or selected working groups

TABLE B-1

ARMY PROGRAM ADVISORY GROUP FOR BDAR

Chairman	-	AMC DCSSMT	
Co-Chairman	-	Army Materiel Systems Analysis Activity (AMSSA)	
Co-Chairman	-	Materiel Readiness Support Activity (MRSA)	
Secretary	-	AMSSA	
Representatives:			
		HQDA Deputy Chief of Staff for Logistics	Missile Command (MICOM)
		AMSSA	Communications-Electronics Command (CECOM)
		Ballistics Research Laboratory (BRL)	Armament, Munitions and Chemical Command (AMCCOM)
		Tank-Automotive Command (TACOM)	Training and Doctrine Command (TRADOC)
		MRSA	U. S. Army Logistics Center (USALOGCEN)
		Aviation Systems Command (AVSCOM)	U.S. Army Aviation Logistics School (USAALS)
		Troop Support Command (TROSCOM)	U. S. Army Ordnance Center and School (USAOC&S)

and provide necessary guidance and direction. The current four working groups are as follows:

1. *Doctrine, Policy, and Training Group*: Chaired by HQTRADOC
2. *BDAR in Logistics Support Analysis (LSA) Process*: Chaired by Materiel Readiness Support Agency (MRSA)
3. *Publications*: Chaired by MRSA
4. *Field Trials*: Chaired by the Army Materiel Systems Analysis Activity (AMSSA).

Minutes of PAG meetings are distributed to all AMC organizations, all major worldwide Army commands, and Navy and Air Force battle damage and repair offices [NAVAIR 41 and Wright Research and Development Center/FIVST (WRDC/FIVST) and Surviac]. The co-chairmen of the PAG are responsible for the timely completion of outstanding actions noted in the PAG minutes.

ARMY BDAR POLICY

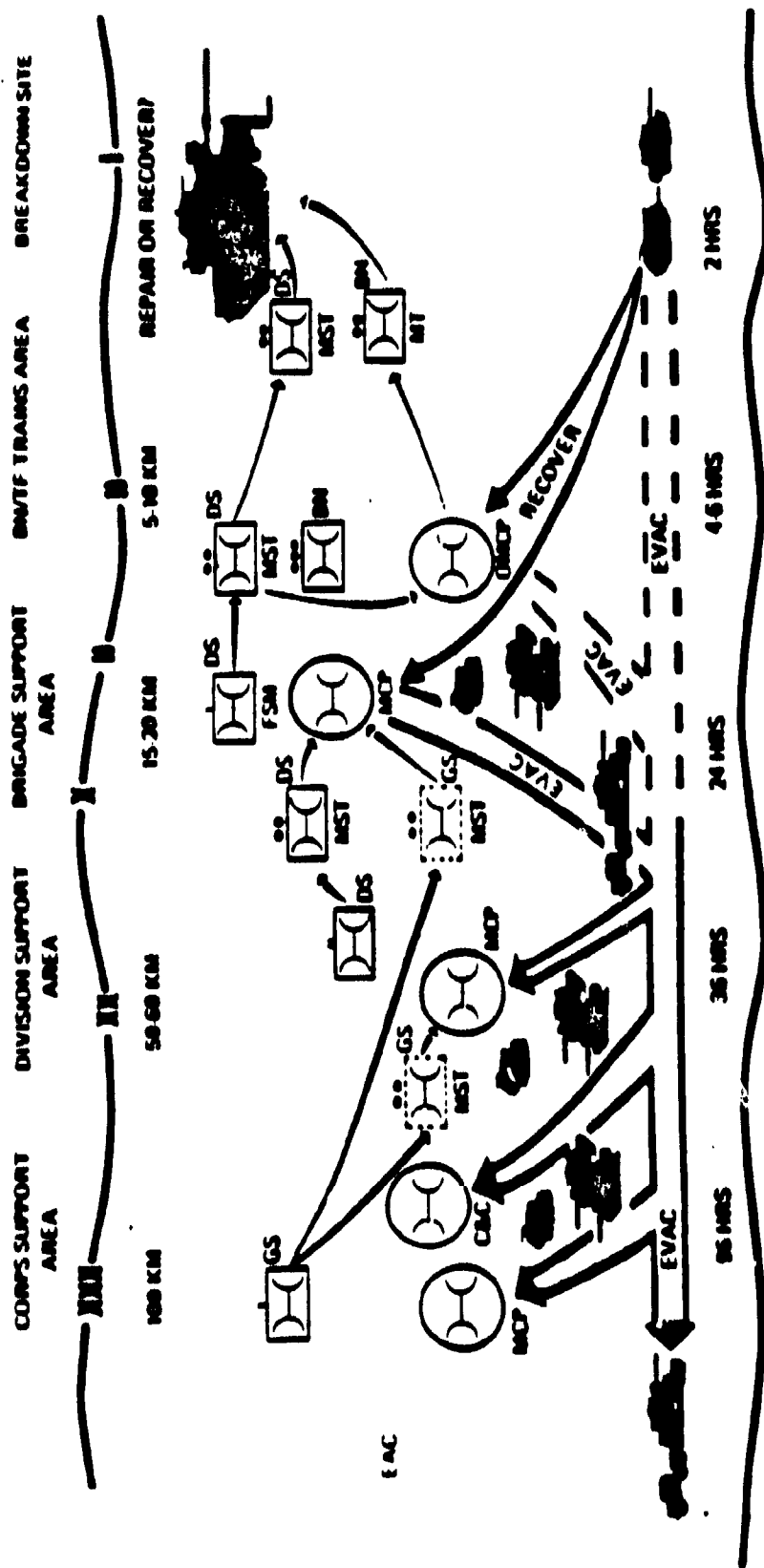
The Army's BDAR policy is defined in Army maintenance regulation AR 750-1. BDAR is to be conducted as far forward as possible in order to return disabled equipment to the operational commander rapidly. BDAR is viewed as a supplement

to standard Army maintenance procedures, to be used only when it is impractical to apply the standard fix. BDAR procedures include rapid assessment of system problems and then either the deferment of maintenance or the application of expedient fixes, such as by-passing, replacing, or jury-rigging components to restore the minimum essential systems required for the support of a specific combat mission or to enable the equipment to self-recover.

A key provision of the policy states that BDAR fixes are authorized only for use in an emergency combat situation and only at the direction of the commander. (This provision is currently under review by the Army – see paragraph below on publications.) The BDAR fixes have been developed for use by the organic operator/crews, unit, and intermediate maintenance personnel and support teams. Unlike that of the Air Force, the Army's BDAR policy does not include special contact teams developed or trained specifically for BDAR. The BDAR fixes do not have to restore the full performance capability of the vehicle or helicopter, i.e., degradation in performance is acceptable as a rule, but the vehicle or helicopter must meet minimum essential combat capability to effectively shoot, move, and communicate. The Army program includes all failures and malfunctions on the battlefield, including random failures, wearouts, accidents, and operator errors as well as ballistic damage.

Key to the battlefield repair of damaged/inoperative Army equipment is an assessor [usually a senior noncommissioned officer (NCO)] who, on the basis of specific BDAR training and systems knowledge of the equipment, can determine what needs to be fixed, how long it will take, and where it should be done. The Army publishes repair time limit guidelines for determining the repair site for ground vehicles as follows (see Figure B-1).

- *Two hours* – repair at breakdown site
- *Four to six hours* – repair at Battalion trains
- *Twenty-four hours* – repair at Brigade Support Area
- *Thirty-six hours* – repair at Division Support Area
- *Ninety-six hours* – repair at Corps Support Area.



Repair time limits (hours) are provided as guidelines to be adjusted on the basis of the tactical situation

FIG. B-1. U.S. ARMY MAINTENANCE BATTLE

Vehicles damaged and repaired will be separated into five categories as follows:

- *Fully Mission Capable (FMC)* – can perform all required missions safely.
- *Combat Capable (CC)* – meets minimum functional combat capability criteria.
- *Combat Emergency Capable (CEC)* – functionally adequate for a specific combat mission at commander's discretion.
- *Self-Recoverable (SR)* – adequate mobility for self-recovery – may involve hazardous conditions.
- *Non-Self-Recoverable (NSR)* – candidate for cannibalization of repair parts or components.

BDAR repairs will attempt, on the basis of mission needs, to upgrade the maximum number of vehicles to a higher category than the one in which they were originally found.

For aviation assets, the Army's program is referred to as Aircraft Combat Maintenance/Battle Damage Repair (ACM/BDR). ACM/BDR is the responsibility of the Aviation Unit Maintenance (AVUM) level, with Aviation Intermediate Maintenance (AVIM) providing backup. Quick-fix/BDR techniques have been developed to return the maximum number of aircraft to service in as little time as possible, with the goal of completing most repairs within 4 hours. Damaged aircraft will be put into categories by a damage assessor in the same fashion as ground vehicles. Some aircraft will be returned to service immediately through deferment of non-safety-of-flight maintenance; some will be designated for specific on-site quick-fix repairs using BDR; others that require more extensive repairs taking 8 – 72 hours will be recovered and set aside for repair as resources are available. Aircraft that cannot be repaired within 72 hours will be cannibalized for serviceable components and systems to be used to return other aircraft to mission capable condition. ACM/BDR maintenance actions fall into five categories:

- *Low-Risk Defer* – continue unlimited combat operations for a minimum of 100 hours; cosmetic repair only
- *High-Risk Defer* – capable of unlimited combat operations at discretion of unit commander

- *One-Time Flight* — capable of controlled flight (limited envelope) to a repair facility
- *Repair* — to permit unlimited combat operations for a minimum of 100 flight hours
- *Scrap-Cannibalize* — aircraft unrepairable within time and support limits.

NEED FOR BDAR

The Army, in formalizing its BDAR program, recognizes that it must be able to fight in an intense, highly lethal environment for a sustained period with what it has on hand. Its ability to restore and return damaged weapon systems to battle will be a distinct advantage. Our European allies have recognized this for some time. They have for years had a BDAR working group under the European Logistics Organization (EUROLOG), to which the United States has been an observer only. Recently, however, the NATO Military Agency for Standardization (MAS) Army Board has formed (January 1989) a working party (WP) on Battlefield Recovery, Repair, and Evacuation in which the United States will be actively involved. The U.S. will provide the chairman (from the Army Ordnance Center and School) and a U.S. representative (from AMC). The purpose of the WP is to develop standardization of doctrine, policy, procedures, equipment, and systems for battle-field recovery, repair, and evacuation. The group's primary focus will be battle damage repair.

Analyses of the results of the 1973 Arab-Israeli war showed the impact and lethality of modern weapons in a conventional war and gave impetus to the Army's program. Records for that war reveal that in the first 18 hours of battle, about 75 percent of Israeli-available tanks were damaged (346 out of 450). But approximately 80 percent of the damaged tanks were returned to the battle in less than 24 hours. Some tanks were restored four or five times during the course of the 2-week war.¹ The Israelis credit this capability for turning the tide of battle, particularly in the Golan Heights.

¹1986 Proceedings-Annual Reliability and Maintainability Symposium, p. 490.

U.S. Army analyses show similar results. By combining the results of its combat simulation models with the Spare Component Requirements for Combat (SPARC) model, the Army can estimate how many weapon systems and what parts would be damaged and repairable. One such USAMSAA analysis for M60A3 tanks in a European environment showed over 1,400 tanks requiring repair based on a starting force of 1,190 tanks over a 180-day war, with most occurrences in the first 30 days (the number of repairable tanks exceeds the force because some tanks would be repaired more than once). The Army recognizes that advanced combat systems such as the M1 tank have significantly better survivability characteristics than predecessor systems. These highly survivable systems will produce even more vehicles for repair of combat damage. The Army estimates that the percentage of combat damage incidents involving the M1 in which the tank will be repairable is greater than twice the percentage of repairable incidents for the M60A3 tanks.

For aviation, the Army recognized the need for a BDAR capability in its Combat Service Support Mission Area Analysis (MAA) completed in 1982. This analysis showed that increased flying hours per month could be achieved with a BDAR capability for all types of Army helicopters. The MAA (Chapter 3 - Aviation) showed increased flying hour rates by type of helicopter (see Table B-2).

TABLE B-2
IMPACT OF BDAR

Helicopter type	Percent increase in flying hours per month
UH-60A	+ 18
AH-64	+ 24
AH-1S	+ 48
CH-47D	+ 57
OH-58C	+ 119

Another way of showing the impact of BDAR is depicted in Figure B-2, which shows that, with attrition rates of 3 to 5 percent and combat damage rates of 15 to 25 percent, a fleet of 100 helicopters without a BDR repair capability would be almost wiped out after 20 sorties. With a perfect repair capability (all damaged helicopters repaired within 6 hours), 40 to 65 percent of the fleet would still be available for combat after 20 sorties. Shown still another way in Figure B-3, the cumulative number of sorties flown over 10 days (assuming four sorties per day) is almost six times as great with perfect repair as opposed to no repair. It is clear that a battle damage assessment and repair capability is a significant combat multiplier for both ground vehicles and helicopters.

BDAR IN RESEARCH AND WEAPONS DEVELOPMENT

Research and Advanced Technology

As with the other Services, the Army BDAR program is pursuing a modest research and advanced technology effort. At the Army Materials Technology Lab (MTL), the Aviation Applied Technology Lab, and other Army test facilities, studies are being conducted on the damage tolerance of fiberglass composites, the toxic fumes problem that occurs when composites burn, the reparability of composites struck by ballistics, and the development of several BDAR repair kits for ground vehicles and helicopters.

This research is important because new weapons systems are using composite materiel in place of materials such as welded aluminum armor. For example, the Army recently successfully completed an all-composite infantry vehicle turret test and also awarded a 4-year, \$13 million contract to develop a prototype infantry fighting vehicle with a composite hull. Additionally, the Army is investigating modular design concepts and composite repair techniques for helicopters and is looking at the utility of using thermoplastics for repair.

For ground vehicles, the Army TACOM has several R&D initiatives underway. A generic hydraulic repair kit is in the development phase. It will contain generic hoses and fittings and other essential materials that can be used to repair practically any damaged hydraulic lines. Research is also being conducted to develop methods, procedures, and equipment to repair damaged fuel cell bladders that have plastic linings. Work continues on a fiberglass patch technique for fuel cell repair, with an estimated completion date in 1990. For telecommunications assets, the Army

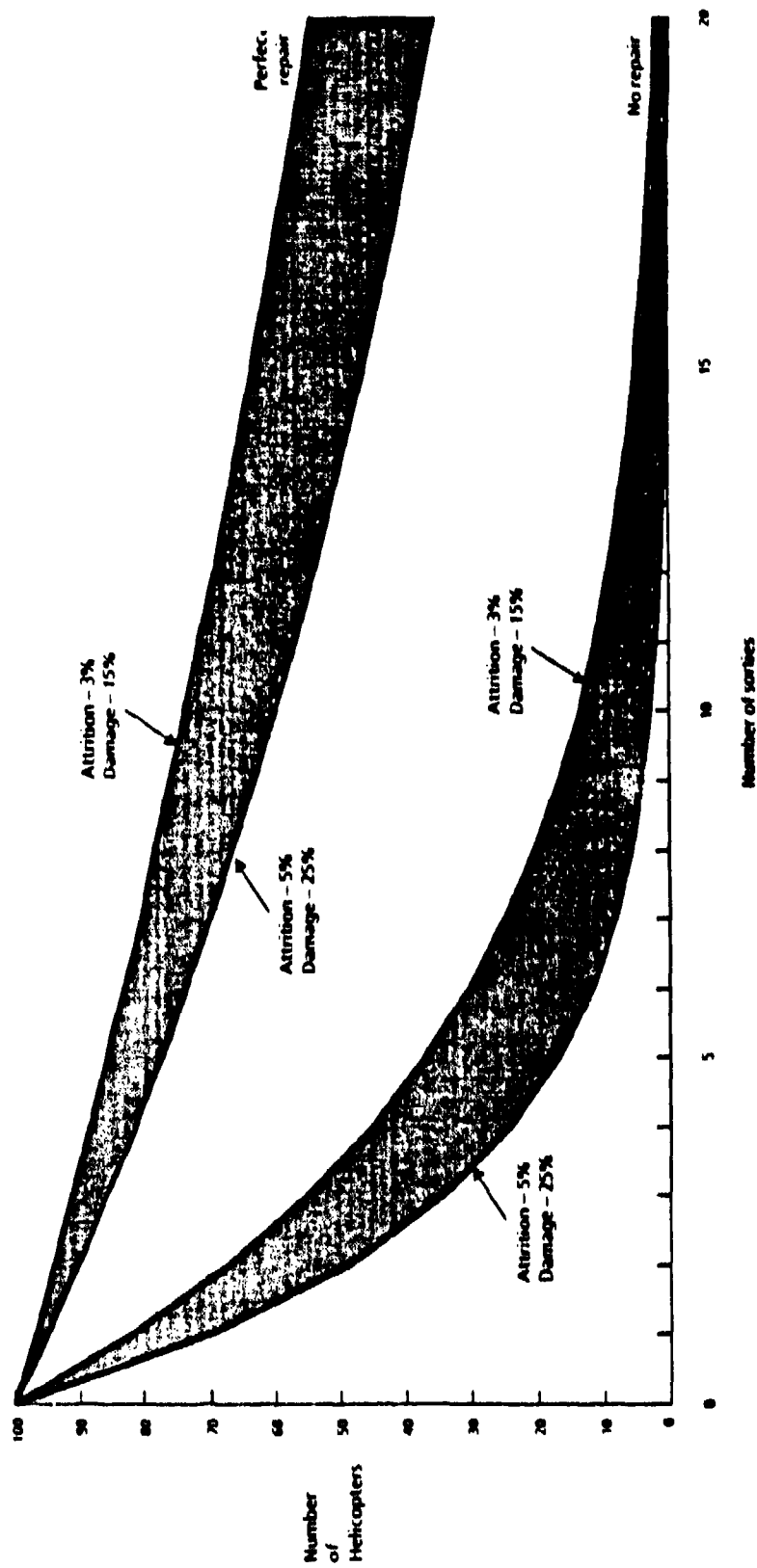


FIG. B-2. HELICOPTERS AVAILABLE VERSUS REPAIR CAPABILITY

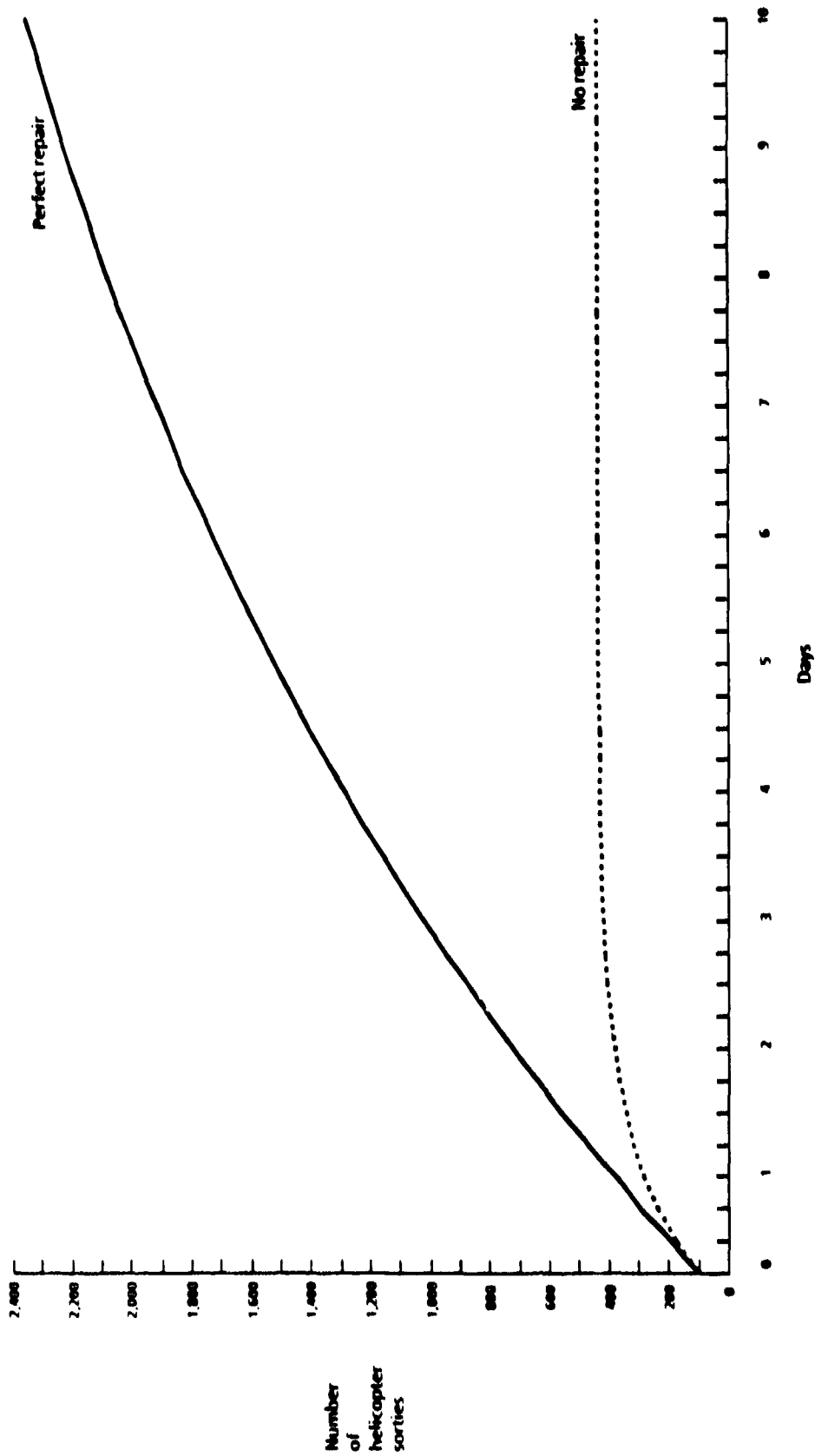


FIG. B-3. SORTIES FLOWN VERSUS REPAIR CAPABILITY
(Four sorties per day/100 helicopters)

(CECOM) has developed, tested, and approved for production a fiber-optic splicing repair kit. This portable (suitcase-size) kit provides the capability to clean, splice, and fuse damaged optic fibers and could be used to repair fiber-optic wiring expected to be in new weapons systems. The kit has been type classified, and the Army expects to award a production contract this year and have the kit in the field by FY91 – FY92. In order to meet BDAR needs the Army has designed and tested a field repairable vehicle radiator. The radiator still needs a field condition test to determine whether it meets system requirements.

In the wire repair area, research is underway to determine the best means of identifying critical wires in wire bundles/harnesses (e.g., by color-coding or wire tag) and to design and develop a kit to assist the soldier in doing his repair job. The Army is also investigating how to make wiring harnesses more BDAR supportable.

Funding for BDAR R&D efforts remains a continuing problem. Very often funds are not available under a BDAR-specific project but are a subset of funds for another R&D project. Despite almost a decade of R&D for BDAR aviation repair kits, the capability has not moved from the laboratory to the field. Very few BDAR kits have been procured.

Design

The Army recognizes the importance of designing features into weapon systems that will enhance the ability of combat crews and maintenance teams to assess damage and apply BDAR fixes to their systems rapidly and effectively. The USA Materiel System Analysis Activity has published general guidelines² for use by materiel developers to assist them in incorporating BDAR considerations and combat resilience principles into the planning and developing of Army materiel systems.

Unfortunately, incorporation of these BDAR design principles into new weapon systems has not received the emphasis or priority afforded other design criteria such as performance and survivability, or they have been traded off because of overriding space, weight, and cost considerations. In fact, in some cases, the ability to apply field fixes has decreased as a result of "product improvements." For example, the attack helicopter, the AH-1, has gone through many product improvements since being

²Special Publication No. 40. *Primer: Design for BDAR*. USAMSAA, Aberdeen Proving Ground, Maryland. Apr 1986.

fielded in the mid-1960s. An important design change affecting BDAR has been the elimination of the wire harness disconnects in the fully modernized AH-1S. All previous configurations had tail boom disconnects and separate tail boom harness segments. For a reported weight savings of 30 pounds, this single design change was responsible for making any forward repair of battle-damaged tail booms virtually impossible. The elapsed maintenance time for such repairs is now over 100 hours, compared to the 6 hours previously required.³ Without the disconnects, a repair now involves removal of all boom wiring, repair of harnesses, installation of a new boom assembly, installation of repaired harnesses into new boom, and checkout of TOW operational status. In previous models, a new boom assembly, with wire harness segments already incorporated, could be installed as a replacement for the damaged tail boom. Tail boom hits were the most prevalent type of battle damage in Vietnam, responsible for grounding about one-third of the helicopter inventory for the entire theater each year.⁴

The Army is now developing a new composite helicopter — the Light Helicopter Experimental (LHX). The LHX represents the best opportunity for the Army to make BDAR have a major impact on a new weapon system design. Although AVSCOM is actively promoting BDAR in the design of the LHX, it is currently being handled under the Reliability, Availability, Maintainability (RAM) umbrella and consequently does not have the visibility or emphasis of these well-entrenched programs.

BDAR is addressed in the LHX System Specification document and in the LHX Request for Proposal (RFP). The System Specification document states the requirement for BDAR as: "The Contractor shall develop Combat Maintenance/Battle Damage Repair (CM/BDR) procedures," and more specifically, "CM/BDR component/line replacement maintenance/line replacement unit/subsystem maximum time to repair shall not exceed 3 hours, 95 percent of the time." Assuming one hit and available maintenance personnel supporting combat unit flight operations using ACM/BDR activities, the contractor is also to provide, for the LHX,

³U.S. Army Aviation Research and Development Command TR-82-D17. "Wiring Inspection and Repair Techniques." Fort Eustis, Virginia: Applied Technology Laboratory. Oct 1982. USGO.

⁴LM Report ML104. *Fix Forward: A Comparison of the Army's Requirements and Capabilities for Forward Support Maintenance*. Nauta, Frans. Apr 1983.

a CFI⁵ on the probabilities of repair of damage within 24 hours and 72 hours. Under the LHX maintenance planning concept for ACM/BDR, quick-fix assessment/repair techniques for combat damage are to be developed to enable the aircraft to operate for a limited time (100 flight hours); however, it is not specified at what operational capability level the aircraft will operate. The System Specifications also require maintainability demonstrations to include separate hot bench and on-aircraft tests to verify diagnostic performance and BDR capability. Unfortunately, there is less emphasis in the LHX RFP. Although AVSCOM logistics personnel are emphasizing BDAR, it is not supported very effectively in the LHX primary acquisition documentation.

It is essential that the Army provide full support for BDAR as an integral design and operational feature in the LHX. BDAR was an integral part of the design criteria and acquisition process of the LHX T-800 engine contract, which successfully demonstrated "hot bench" and "on aircraft" BDAR tests. The contractor, Allison and Garrett, demonstrated that BDAR could be accomplished with the Army-developed repair kits and techniques within the time limits specified by AVSCOM. AVSCOM personnel advocate BDAR considerations in the development phase of the LHX airframe and believe that the prime competing contractors realize that BDAR will be a primary consideration in the weighted selection process determining the winning team. However, increased emphasis and specific objectives for BDAR capability need to be documented in the acquisition documents (i.e., RFP, System Specs, ILS).

The modular concept inherent in the Integrated Communications/Navigation Identification Avionics (ICNIA) and Integrated Electronic Warfare System (INEWS) modules being developed for the LHX weapon systems could have a positive impact on BDAR. The Army is promoting the interoperability and compatibility of the ICNIA and INEWS modules as a tri-service common electronic architecture suitable for use in the Navy ATA and Air Force ATF weapon systems. The BDAR benefit of the modular compatibility is that, through enhancing the potential for cross unit/service cannibalization, it increases the likelihood of having an available spare.

LIVE-FIRE TESTS

The Army's live-fire test program for BDAR has been limited, with only one scheduled recurring event. For the past 3 years, the Army has participated in the

⁵Contractor Furnished Information — the actual value is to be furnished by the contractor.

Federal Republic of Germany's BDAR field trials. The Germans have been conducting these annual trials at Meppen, Germany for the past 7 years. The United Kingdom joined the trials 2 years ago. The Army also used the congressionally mandated live fire tests of the M1 main battle tank (MBT) conducted at Aberdeen Proving Ground, Maryland, during 1987 - 1988 for collecting BDAR information.

At Meppen, the Army has used 14 different U.S. combat vehicles and pieces of equipment and subjected them to indirect firing and nonpenetrating direct firings. In Meppen 88, direct-fire penetrating shots against the M60A3 MBT were used for the first time. Although these joint live-fire tests have been limited by funds, time, personnel, and equipment, they have proven useful for several reasons, including (1) validation of existing BDAR methods and development of new BDAR procedures, (2) hands-on BDAR training for about 20 - 25 soldiers per year, (3) collection of data for use in the Army's SPARC model (e.g., vulnerability, survivability, and ballistic damage information), and (4) development of interoperable vehicle repair and recovery operations with several key NATO allies. Plans for Meppen 89 tentatively include using helicopters for the first time (UH-1/OH-58) and latest generation tracked combat vehicles (the M1, M2, and the M113A2 with external fuel cells).

As useful as these trials have been, the results must be tempered by the primary restrictions of the field trials: (1) the firings were designed to limit the amount of catastrophic damage to the vehicles and (2) the MBT did not have ammunition on board, nor were hydraulic systems under pressure. The Army's Meppen 88 after-action report emphasized that to reap fully the benefits from trials of this type, funding must be provided to translate the lessons learned into real BDAR improvements and modifications to existing equipment and to ensure that BDAR requirements are included in the development of new equipment. The AMC commands such as TACOM have the responsibility to incorporate the lessons learned into the BDAR technical manuals (TMs) and to influence weapon systems design and modifications accordingly.

The M1 live-fire tests took place from August 1987 to July 1988 at Aberdeen Proving Ground, Maryland. The OC&S, together with the Ballistic Research Laboratory (BRL) and AMSAA, formed a BDAR maintenance team to assess and fix the damage caused by 54 selected shots (rocket propelled grenades, missiles, etc.) at five different M1 or M1A1 tanks. The team was able to fix most of the selected damage on the tanks (only 3 out of 54 were not fixable). These very positive results

must be balanced against the fact that the more severe damage was not selected to be fixed (e.g., the gas turbine engine), and some key components for operational effectiveness of the tank such as the laser range finder, fire control computer, and gun elevation mechanisms could not be fixed. The team also did not attempt to repair armor damage and the repairs were not subject to extensive stress testing. The most significant problem uncovered during this BDAR experience was the difficulty in repairing electrical wires, which are marked on the M1 only at the connector (6-12 inches away). The BDAR team strongly recommended that all wires on the M1 be color coded or marked every 6 inches to facilitate wire identification and repair. Some of the M1 wire harnesses are 2 to 4 inches thick and contain up to 128 wires.

The repairs on the M1 were conducted on a "worst case" basis in that no special tools, repair parts, or cannibalization of components were used by the BDAR team. The extremely knowledgeable personnel on the team, however, proved that diagnostic skills are the key to effective BDAR. Whether the Army will continue to take advantage of these live-fire tests by testing BDAR procedures in the future remains to be seen. BRL is strongly supportive of this approach.

Even though the Army's attempts to gain BDAR experience through live-fire tests have been limited and often constrained, valuable data have been accumulated. A systematic live-fire program designed specifically for BDAR would provide dramatic qualitative increases in the Army's BDAR knowledge and procedures and form the basis for weapon systems design criteria.

LOGISTICS PLANNING FOR BDAR

A complete BDAR program should include provisions for special technical publications, kits, spares, and training. The Army program has considered each of these logistics areas with various levels of accomplishment. Each area is discussed in detail below.

Publications

Since 1982, the Army has focused primarily on developing TMs for BDAR. To date 15 TMs have been published on ground vehicles and support equipment (see Table B-3 for a complete list). The initial aviation manuals have been in draft for quite some time and should be published by June 1989.

TABLE B-3
ARMY BDAR TECHNICAL MANUALS

Title	Number	Original publication date ^a
M1 Tank	9-2350-255-BD	December 1983
M48/M60 Tank	9-2350-273-BD	January 1984
M109 Howitzer	9-2350-274-BD	January 1984
M113 APC	9-2350-275-BD	February 1984
General Combat Vehicle	9-2350-276-BD	February 1984
Chaparral	9-1425-1586-BD	December 1984
Comm-EI	11-5800-215-BD	September 1986
M2/M3 IFV/CFV	9-2350-252-BD	May 1987
Lance	9-1425-485-BD	June 1987
M102	9-1000-257-BD	September 1987
Chem Def Mat	3-251-BD	September 1987
TAC Vehicle	9-2320-356-BD	December 1987
M198	9-1000-258-BD	January 1988
PIVADS	9-1005-321-BD	January 1988
Generators	5-6115-624-BD	March 1988
MLRS	9-1425-646-BD	TBP (June 1990)
Pol Equipment	5-3835-272-BD	TBP (April 1989)
Air Conditioners	5-4120-394-BD	TBP (date unknown)
AH-1 Helicopter	55-1520-244-BD	TBP (June 1989)
OH-58A/C Helicopter	35-1520-228-BD	TBP (June 1989)
OH-58D Helicopter	Unknown	TBP (August 1990)
UH-60 Helicopter ^b	55-1520-237-BD	TBP (in rewrite)
CH-47 Helicopter	Unknown	TBP (March 1990)
UH-1 Helicopter	Unknown	TBP (November 1989)
AH-64 Helicopter	Unknown	TBP (October 1990)
M9 ACE	Unknown	TBP (January 1989)
HET	Unknown	TBP (August 1989)
M88A1E1 Recovery Vehicle	Unknown	TBP (October 1990)

Note: TBP - To be published

^a Subsequent changes to the original publication dates are not shown

^b Joint development with Air Force.

AR 750-1 states that not all equipment will need a BDAR TM. The need for a BDAR TM is left to the discretion of the AMC major subordinate command (MSC) materiel developer (e.g., AVSCOM for helicopters; TACOM for ground tactical vehicles). The general guidance in the regulation is that TM development should concentrate on those items of equipment that have a significant impact on the outcome of a specific combat mission. Selection considerations are:

- Primary equipment/weapon systems
- Location in the forward battle area
- Equipment influencing the mission in the forward battle area
- Logistical support considerations
- Density of equipment.

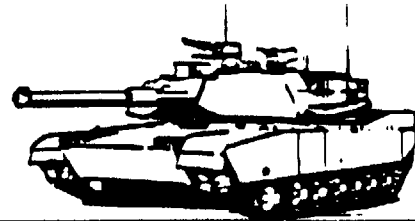
The two-letter suffix "BD" is used in place of the normal category of maintenance number to indicate that BDAR techniques are usable at all levels of repair. MIL-M-63003 (TM) provides detailed guidance on format and development of BDAR TMs.

These BDAR manuals are organized by subsystem on the vehicle (e.g., engine, transmission, fuel, etc.). Figure B-4 is an example of the organization of a typical BDAR TM. Each chapter generally provides fault assessment tables and procedures, expedient repair procedures, and a detailed index for finding a specific assessment or repair procedure quickly. Appendices are used to list such things as special BDAR supplies needed, petroleum, oil, and lubricant substitutes, and interchangeable parts from other weapon systems. Liberal use of drawings and diagrams is made in the TMs for clarification and ease of use.

Future weapon systems development such as the LHX will require the contractor to provide the battle damage TM. In several cases already, particularly for helicopters, the TM has been developed under contract.

TECHNICAL MANUAL

**OPERATORS, ORGANIZATIONAL,
DIRECT SUPPORT AND
GENERAL SUPPORT MAINTENANCE**



**BATTLEFIELD DAMAGE
ASSESSMENT AND REPAIR**

FOR

M1 ABRAMS
TANK, COMBAT
FULL-TRACKED
105-MM GUN

(2350-01-061-2445)

CHAPTER 1	INTRODUCTION	>
CHAPTER 2	ASSESSING BATTLEFIELD DAMAGE	>
CHAPTER 3	ENGINE SYSTEMS	>
CHAPTER 4	TRANSMISSION AND FINAL DRIVES	>
CHAPTER 5	FUEL SUPPLY SYSTEM	>
CHAPTER 6	ELECTRICAL POWER DISTRIBUTION	>
CHAPTER 7	TRACK AND SUSPENSION	>
CHAPTER 8	HYDRAULIC SYSTEM	>
CHAPTER 9	ARMOR AND AMMO STOWAGE	>
CHAPTER 10	ARMAMENT AND FIRE CONTROL	>
CHAPTER 11	COMMUNICATIONS SYSTEM	>
CHAPTER 12	ANCILLARY EQUIPMENT	>
APPENDIX A	BDAR SUPPLIES	>
APPENDIX B	POL SUBSTITUTES	>
APPENDIX C	INTERCHANGEABLE PARTS	>

HEADQUARTERS, DEPARTMENT OF THE ARMY

DECEMBER 1983

FIG. B-4. ORGANIZATION OF TYPICAL BDAR TECHNICAL MANUAL

One drawback to the effectiveness of the TMs is the warning restriction at the top of each chapter, which reads as follows:

"BDAR FIXES SHALL BE USED ONLY IN COMBAT AT THE DISCRETION OF THE COMMANDER AND SHALL BE REPAIRED BY STANDARD MAINTENANCE PROCEDURES AS SOON AS PRACTICABLE AFTER THE MISSION IS COMPLETED."

This warning has resulted in a reluctance on the part of the field units to conduct BDAR training for fear of violating this policy and damaging equipment, thereby adversely affecting readiness reports. The Army has recognized this problem and is attempting to identify those BDAR fixes that can be authorized for peacetime training. Each MSC is to conduct this assessment and will change its TMs by adding an Appendix E listing all authorized peacetime training procedures and "boxing-in" the same procedures in the index. This process is planned to be completed during summer 1989.

Each AMC MSC is writing or has published a separate internal Standing Operation Procedures for BDAR. These manuals are as follows:

- TACOM Regulation 750-XX (TBP)
- TROSCOM Regulation 70-2 (TBP)
- MICOM Regulation 750-8 (11 February 1988)
- CECOM Regulation 750-31 (15 October 1987)
- AMCCOM Regulation 750-5 (TBP)
- AVSCOM Regulation 750-XX (TBP).

In addition, AMC is drafting a manual (AMC Pamphlet 750-XX) that will cover BDAR in the equipment design and acquisition process. It should provide specific representative language for inclusion in contracts, Statements of Work, RFPs, etc. AR 70-1, *Systems Acquisition*, has incorporated some BDAR language, but the language could be strengthened to be more of a "requirement" than a "consideration" for design and testing.

To support the inclusion of BDAR in the LSA process, the Army has proposed a change to MIL-STD-1388-2A to add a "task function code" for BDAR. This change will provide the capability to sort and select data by task function code, allowing

BDAR data to be isolated for analysis and inclusion in BDAR TMs. The Joint LSA working group approved this change in July 1988, with a projected implementation date of December 1989.

BDAR Kits

The Army AVSCOM has developed three aviation prototype BDAR kits for repair of wiring, fuel pods, and fluid lines. There are plans to develop a composite structures repair kit in the FY90 – FY92 time period and an optical component repair kit by the FY91 – FY93 timeframe. As discussed previously in the R&D paragraph, the Army TACOM has R&D efforts for kits for ground vehicles for wire repair, fluid and hydraulic repair, and reservoir repair.

With the exception of 41 connector kits (one part of the aviation wire repair kit), which have been procured and delivered to AH-64 and special forces units, no kits for either helicopters or ground vehicles have been procured or fielded. Each type of aviation kit is on hand at the USAALS for training and at HQs AVSCOM for demonstration, but procurement has suffered from lack of funds and priorities. As of spring 1989, the aviation kits were priority number 117 on the AVSCOM unfunded requirements list. Some stock funds have been made available (\$5 million in FY89) on a user-reimbursable basis for units to purchase the aviation kits. The wire repair kit is the most expensive of the three (\$40,000); the fluids kit costs about \$25,000; and the fuel pod kit is only \$2,000. The AVSCOM estimates total dollars needed for these kits to outfit all appropriate Army units to be approximately \$43 million (see Table B-4).

TABLE B-4
REQUIREMENTS FOR ARMY BDAR AVIATION KITS

Aviation kit	Number of kits	Unit cost	Total cost
Wiring repair	728	\$40,000	\$29.12 million
Fuel cell repair	1,524	2,000	3.04 million
Fluid line repair	460	25,000	11.50 million
Totals	2,712	\$67,000	\$43.66 million

Army aviation personnel believe that the wire repairs made with these kits are as good as depot-level maintenance repairs and would, therefore, be a valuable addition to the field's capability. The wiring kit provides 90 – 100 percent of all tools, materiel, and testers required to perform state-of-the-art restoration of electrical wiring systems on all Army helicopters by the AVIM/AVUM units. In contrast, for example, the existing maintenance kit (MK693) provides only 5 percent of the connector tools. The cost of the kits, however, is very high in relative terms for a unit to purchase. If the kits were procured *en masse*, the cost would be reduced, since they would probably go into automated production. Many of the materials in the kit are currently hand made and assembled by the manufacturer (Raychem).

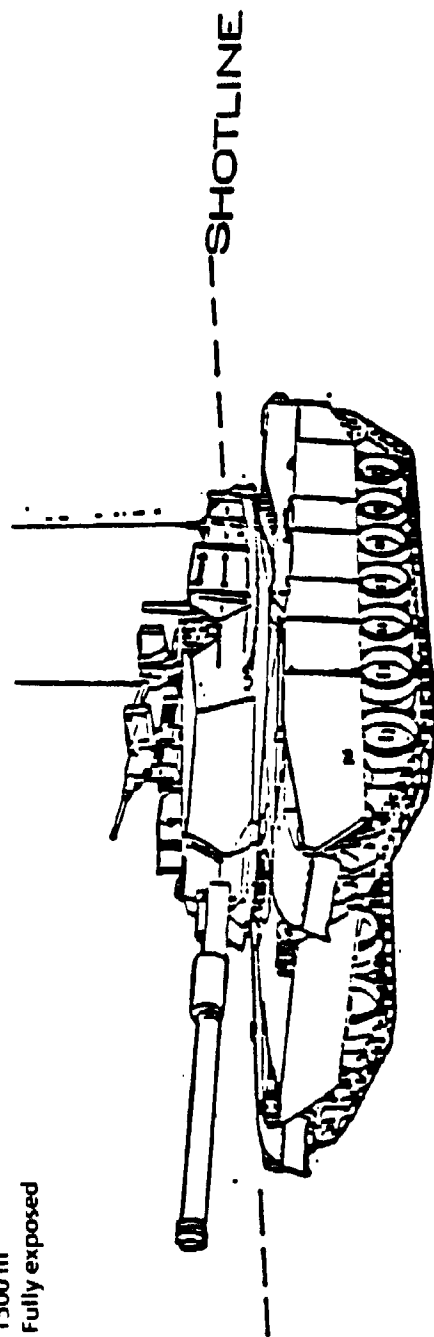
Spares

The Army has not purchased or fielded any spares specifically for BDAR. The Army (AMSAA-BRL) has done a significant amount of work in developing a shotline-based ballistic damage data file for selected weapon systems and has developed a vulnerability methodology for using it in calculating estimates of combat damage repair parts. An example of this methodology is shown in Figure B-5 for the M1 tank. A series of these applications results in the development of a "failure factor (FF) IV" that shows expected use of components for combat damage repair as opposed to replacement because of reliability failures [failure factor (FF) II].

The current method for determining spare parts stockage is based solely on reliability demand data and an increased wartime operating tempo. The main reason for analyzing spare parts requirements for BDAR is to identify components with low stockage for which there will be a much greater need if wartime combat damage is also taken into account. An example is provided by M1 tank components. The 10 most frequently damaged components on the M1 tank, along with their cost and their FF IV and FF II requirements per 100 tanks per year, are depicted in Table B-5. It can readily be seen that the wartime demand (based on FF IV) is radically different from demand based on reliability failures only and that, in many instances, the parts with the highest rate of combat damage have relatively low or no need to be replaced in peacetime. Another example of this difference is the 10 most frequently used parts for the AH-1S attack helicopter, considering reliability failures only versus combat damage only. They are significantly different. Only two items are in common (see Figure B-6). Further, for the most frequently damaged part, the main rotor blade, the mandatory parts list (MPL) for the AH-1S combat prescribed load list (PLL)

Condition

Target: M1
Weapon: 125mm KE
Range: 1500 m
Exposure: Fully exposed



<u>Probability of occurrence</u>	<u>Materiel required</u>	<u>Repair echelon</u>	<u>Time (mh)</u>
0.005	2W102 cable Right front fuel tank Fuel line Driver's periscope	Direct support	25.8

FIG. B-5. METHODOLOGY FOR ESTIMATING COMBAT DAMAGE REPAIR PARTS

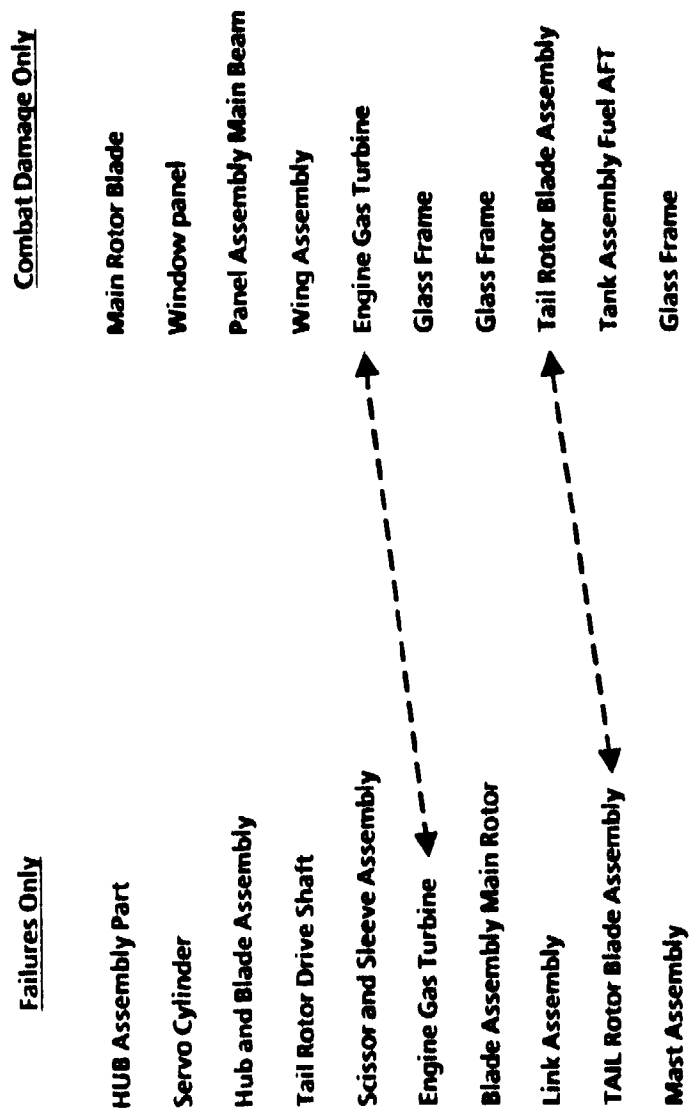
contains no main rotor blades and only one tail rotor blade for this helicopter, regardless of the density of helicopters (Table B-6).

TABLE B-5
TEN MOST FREQUENTLY DAMAGED M1 TANK COMPONENTS

National stock number	Nomenclature	Unit cost	FFIV*	FFII
1230-01-152-5344	GPS Body Assy	\$45,809.00	206	16
5995-00-261-9875	Coax Cable 7059	62.33	126	1
5995-00-889-0757	Coax Cable 4723	55.35	126	1
5995-01-135-7527	Special Cable 13061	60.05	118	NA
5995-01-135-7573	Special Cable 13062	47.35	118	NA
5995-01-135-7574	Special Cable 13063	41.42	118	NA
5995-00-823-2915	Coax Cable 7058	18.95	112	1
1015-01-076-6881	Cable 1W200	2,346.00	103	9
5810-00-892-3343	Remote Frequency Controls	174.00	102	1
1230-01-077-7584	GPS Commander's Extension	1,891.00	95	1

* Replacements for combat damage in terms of items per 100 tanks per year.

Inclusion of this type of analysis for combat PLL/approved stockage list (ASL) stockage development is currently under review by the Army. The Army has approved the inclusion of BDAR spares requirements for selected weapon systems (M1, M60A1, M60A3, M2, and M3) for computation of war reserve stocks (WRS). Other weapon systems will be considered for WRS stocks as data becomes available. For example, BRL has completed its analysis for the AH-64, UH-60, and AH-1S helicopters. Other systems on the Department of the Army (DA) priority list are the M1A1, MLRS, FIST-V, ITV, M109A2, M110A2, and M198. AMC initially estimated that the WRS for the five approved systems with BDAR spares included would cost approximately \$287 million additional for FY89. Funding for this initiative is uncertain at this time.



Source: AMSAA Interim Note No C-97 Sep 1980: p. 75

FIG. B-6. MOST FREQUENTLY USED PARTS (AH-1S)

TABLE B-6

SAMPLE EXTRACT OF MANDATORY PARTS LIST (MPL) FOR AH-1S COMBAT PLL

End Item: Attack Helicopter AH-1S (MOD) PAM 710-2-120

Support Item Name	Unit	1	2	3	4	5	6	7	8	9	10	11	12	14	16	18	20	22	24	26	28	30	32	34	36	40
4010-00-195-2154 BOOM FILTER VAL	EA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2
5300-00-225-0953 COUPLING CLAMP	EA	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3
6610-00-225-6702 MILICOMETER AS	EA	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
5905-00-230-3904 RELAY ELECTRONIC	EA	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3010-00-231-0062 COUPLING FLEMB	EA	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2
5920-00-243-3708 FUSE	EA	2	3	3	3	3	3	4	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7
5330-00-240-3044 PACKINGWREFOHM	EA	2	2	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4	5	5	5	5	5
5330-00-250-0275 PACKINGWREFOHM	EA	3	3	4	4	4	4	5	5	5	5	5	6	6	6	7	7	7	7	7	7	7	7	7	7	7
5330-00-250-0236 PACKINGWREFOHM	EA	3	4	4	5	5	5	6	6	6	6	7	7	7	8	8	9	9	10	10	10	11	11	12	12	13
5330-00-252-4000 PACKINGWREFOHM	EA	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3
1615-00-254-2175 BLADE ROTARY RW	EA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1615-00-254-2191 RETAINER TAIL R	EA	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3
1615-00-254-2205 SHIELD TAIL ROT	EA	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
1615-00-255-2923 COUPLING MANAGER	EA	1	1	2	2	2	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	4
5330-00-263-0011 PACKINGWREFOHM	EA	3	3	3	4	4	4	4	5	5	5	5	5	6	6	6	6	7	7	7	7	7	7	7	7	7
5330-00-263-0030 PACKINGWREFOHM	EA	3	3	3	4	4	4	4	4	5	5	5	5	5	6	6	6	6	6	7	7	7	7	7	7	7
5330-00-263-0033 PACKINGWREFOHM	EA	3	3	4	4	4	5	5	5	5	5	6	6	6	6	7	7	7	7	7	7	7	7	7	7	7

Source: DA Pamphlet 710-2-120 The Army Combat PLL Program 1 February 1988

Note: Only one tail rotor blade authorized, no main rotor blades

The current MPL methodology (Figure B-7) needs to be adjusted to use the ballistic damage file to identify candidate repair part items for combat damage. The proposed combat ASL model should also use the ballistic damage file. The Army's emerging spares policy appears to be based on repairing only when all line replacement units (LRUs) are available and on consolidating all back orders. The Army's goal is to spare to minimize non-mission capable for supply (NMCS). The Army has not yet made a final decision on how best to trade off the probability of increased wartime system availability against the increase in number of lines stocked, and their weight, cube, and cost. The location of stocks and their mobility are also key considerations.

The Army appears convinced that inclusion of spares for BDAR in WRS and possibly in ASLs is required to meet availability goals in combat, but is undecided as to how much monetary and mobility costs it is willing to accept. The Army is analyzing the storage of the combat portion of the ASL at the overseas war reserve storage locations from a management and operational viewpoint.

Training

The Army does not currently have an effective continuous training program for BDAR. No standard training guidance has been given to TRADOC schools or to the field units. The training being conducted at the Army schools (primarily the USAOC&S and USAALS) is mostly familiarization training, with little hands-on experience (see Table B-7). Generally, unit level (both active component and reserve component) training is not being conducted, because commanders are reluctant to use BDAR techniques in peacetime and no BDAR events are included in Army Training and Evaluation Programs (ARTEPS), at the National Training Center (NTC), or in soldiers' qualification testing. An encouraging development is that TRADOC, led by the Logistics Center at Ft. Lee, Virginia, has within the last year has begun to develop a BDAR doctrine, policy, and training action plan, reproduced as Figure B-8. This action plan, was implemented on 1 January 1989.

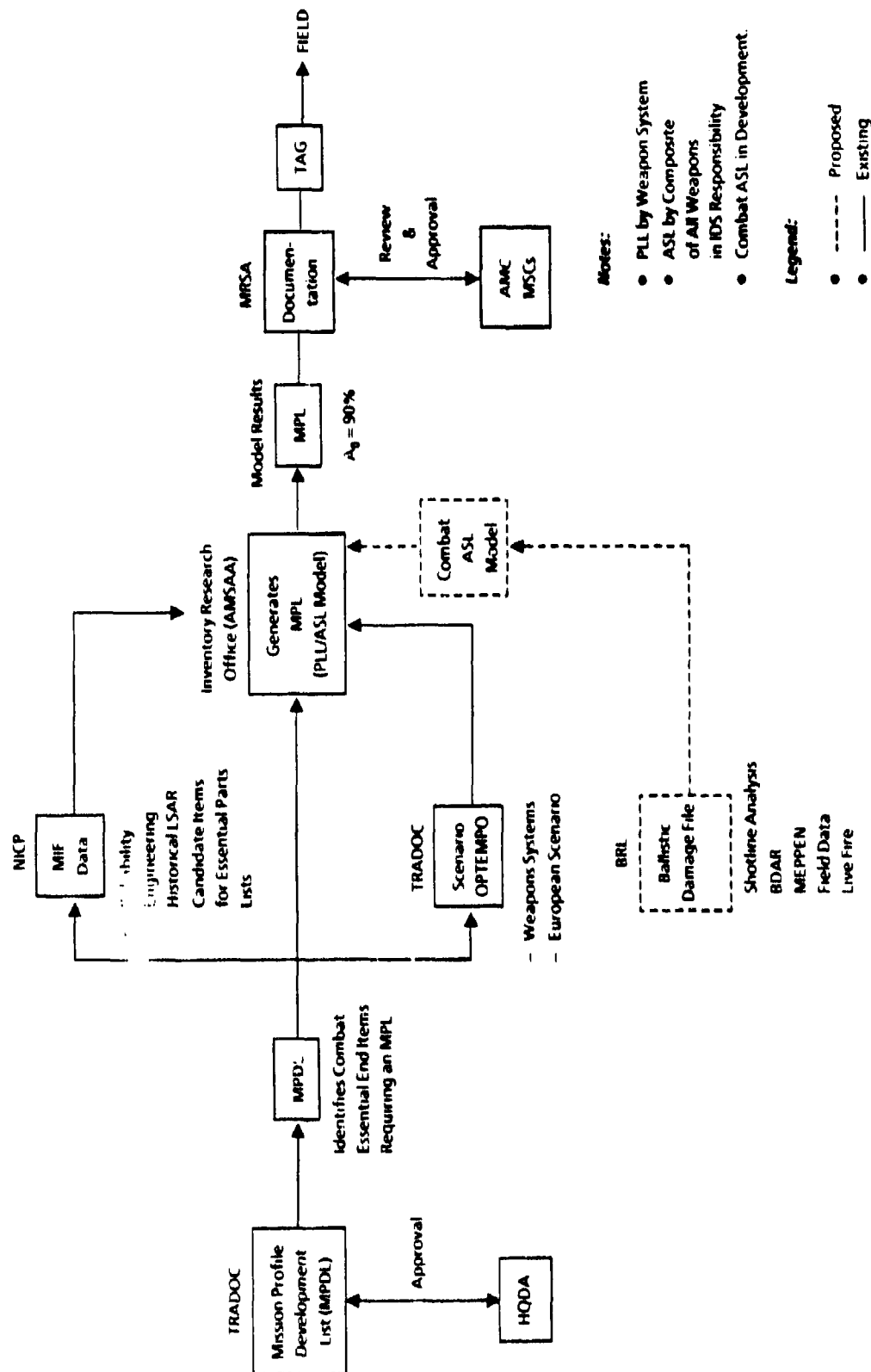


FIG. B-7. MANDATORY PARTS LIST (MPL) DEVELOPMENT PROCESS

TABLE B-7

ARMY SCHOOL TRAINING FOR BDAR

Ordnance School (Aberdeen, Maryland)

AIT - 1 hour (Introduction only)

B/ANCOC - 11 hours (1 Introduction; 2 Manuals; 8 Hands-on Assessment)

WO - 12 hours (same as NCO plus 1 hour BDAR fixes)

LT/CPT - 5 hours (1 Introduction; 2 Manuals; 1 Fix; 1 Build Training Program)

Aviation Logistics School (Ft. Eustis, Virginia)

AIT 2 hours (Introduction)

ANCOC 21 hours (2 Introduction; 19 on Repair Kits)

Familiarization Training at other schools such as the Armor School (Ft. Knox, Kentucky)

Source: USAMSAA USAALS

The military occupation specialties (MOSs) currently receiving training at Army schools are listed in Table B-8. The Aviation School trains MOS 66 and 67 with familiarization training only, and MOSs 68K, 68F, and 68T in the Advanced Noncommissioned Officers Course (ANCOC) course receive 19 hours on the aviation repair kits. USAALS has two helicopters with combat damage that are used for static displays. All repairs are made off the helicopter - mostly on training devices.

The key to effective training is developing the diagnostic skills of the "assessor." USAOC&S, the Armor School, and USAALS are planning to institute or have already instituted additional diagnostic troubleshooting lessons to the Basic Noncommissioned Officers Course (BNCOC) and ANCOC courses. These ANCOC interim courses include an additional 3 weeks of common core diagnostics, followed by specific MOS training. By October 1991 the ANCOC courses will be completely revised to include more hands-on diagnostic training. However, this skill is apparently lacking even for assessing reliability failures. Consequently, the Seventh Army Combined Arms center in Vilseck, Germany has temporarily established a special training course for diagnostic evaluations of failures for the Bradley and Abrams vehicles.

As mentioned earlier, for the past 3 years the Army has conducted limited annual training at live-fire tests at Meppen, Germany for about 20 - 25 mechanics/operators. Although of substantial value to the few individuals involved, this

Milestone/Submilestone	Milestone start date	FY88				FY89				FY90				Estimated comp date	Action LEAD POC
		1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr	1st Qtr	2nd Qtr	3rd Qtr	4th Qtr		
1.00 Develop/write and publish BDAR DPT Action Plan	Jun 88	A					P							Dec 88	LOGC
2.00 Develop/Update MOU between AMC and TRADOC	Jun 88	A					P							Dec 88	TRADOC
3.00 Update/Expand BDAR Training Policy in AR 758.1	Aug 88			A				P						Feb 89	LEA
4.00 Develop/write and publish BDAR Concept Statement	Jun 88	A					P							Dec 88	OCBS
5.00 Develop/write and publish BDAR doctrine in FMs	Jun 88	A										P		Mar 90	All Schs
6.00 Market BDAR as a viable training program	Jun 88	A						P						Feb 89	All Schs
6.10 Develop/write and publish generic lesson plan	Aug 88			A					P					Apr 89	OCBS
6.20 Update and field BDAR video (TVT 9-132 version)	Aug 88			A					P					Apr 87	OCBS
7.00 BDAR training into all Miant related PODs	Aug 88			A								P		Apr 90	All Schs
8.00 Develop/write task in BDAR AMTP	Jun 88	A										P		Apr 90	LOGC/OCBS
9.00 Identify task in BDAR TMs for production training	Aug 88			A								P		Apr 90	AMC/TRADOC
10.00 Conduct BDAR training in Active and Reserve Components NTC	Jan 87					A								VB 2000	All Schs

FROM EMSTATUS

- 1.00 TRADOC wide BDAR DPTWC meeting conducted on 5 Oct 88 finalized action plan with milestone chart . . . action plan will be implemented on 1 Jan 89.
- 2.00 MOU between AMC and TRADOC brainstormed and finalized should be fielded as scheduled.

P Programmed start/completion
A Actual start/completion

Forecast and actual progress

FIG. B-8. ARMY BDAR DOCTRINE, POLICY, AND TRAINING ACTION PLAN

training is a one-time event not reinforced at unit level. The BDAR procedural testing on the M1 during live-fire survivability tests conducted at Aberdeen Proving Grounds falls into the same category. The bottom line is that the Army still faces a tremendous task in establishing effective training procedures for its soldiers. The TRADOC action plan is a step in the right direction.

TABLE B-8

MOSs RECEIVING BDAR TRAINING

Ordnance Center and School	
Metal Worker	44B
Machinist	44E
FC Instrument Repair	41C
FC System Repair	45G
Army/FC Maintenance Supervisor	45Z
Small Arms Repair	45B
Tank Turret Repair	45K
Artillery Repair	45L
Mech Maintenance Supervisor	63Z
Light Wheel Vehicle Mech	63B
Heavy Wheel Vehicle Mech	63S
Track Vehicle Mech	63Y
Fort Sill	
SP FA Trt Mech	45D
SP FA System Mech	63D
Fort Knox	
M1 Trt Mech	45E
M1 System Mech	63E
M60A1/A3 Trt Mech	45N
M60A1/A3 Tank System Mech	63N
BFVS Trt Mech	45T
BFVS System Mech	63T

TABLE B-8

MOSs RECEIVING BDAR TRAINING (CONTINUED)

Aberdeen Proving Ground	
Fuel and Elec System Repair	63G
Track Vehicle Repair	63H
Wheeled Vehicle Repair	63W
Fort Leonard Wood	
Const Equipment Repair	62B
Utility Equipment Repair	52C
Power Gen Equipment Repair	52D
Gas Turbine Gen Repair	52F
Fort Eustis Aviation Logistics School	
Aircraft Technical Inspectors	66-All
Aircraft Repairers	67-All
Aircraft Armament /Missile System Repairer	68J
Aircraft Components Repair Supervisor	68K
Aircraft Electrician	68F

OBSERVATIONS

The Army BDAR program is proceeding at a steady, but relatively slow pace. The Army is producing a significant number of technical manuals for BDAR repair procedures and techniques and revising applicable MIL Standards to incorporate the concept of combat resilience. TRADOC is making a strong effort to restudy BDAR doctrine, policy, and training guidance. Some limited Research, Development, and Engineering (RD&E) efforts are underway. For example, TACOM has allocated \$200,000 for its RD&E program for FY89. The LHX program office is attempting to consider BDAR in designing the new helicopter. Army prototype aviation BDAR kits have been developed and are being used in ongoing school training programs, but the kits have not been procured or fielded. The Army BDAR program needs more visibility to elevate BDAR awareness Army-wide. The foundation for a solid BDAR program exists, however, more funding and command emphasis is necessary.

The Army has accepted the importance of BDAR as a combat multiplier. Many diverse programs are underway, with various levels of effectiveness. In order to take

a major step in advancing the Army's fielded BDAR capability, the following actions are needed:

- Obtain funding for BDAR initiatives.
 - ▶ Need to emphasize importance of BDAR to commanders.
 - ▶ Most funding for BDAR is currently "out-of-hide."
 - ▶ BDAR efforts suffer from low priority.
 - ▶ Immediate need to fund procurement of helicopter battle damage repair kits (\$43.6 million over 5 years needed to provide wire repair kit, fuel cells repair kit, and fluid line repair kit to all active component and reserve component aviation maintenance units).
 - ▶ Fund vehicle repair kits.
- Establish BDAR as an integral element of the supportability program for design of Army Materiel Systems.
 - ▶ Program Executive Officers, Program Managers, and ILS managers need to be made aware of their responsibilities for BDAR.
 - ▶ Integrate with ILS, Manpower and Personnel Integration, and RAM programs. BDAR needs to be part of process.
 - ▶ Include BDAR requirements in RFP, SOW, and contracts.
 - ▶ Continue current efforts to include BDAR requirements in LSA/ Logistics Support Analysis and Requirements.
 - ▶ Conduct design/tradeoff study reports for BDAR.
 - ▶ Need to develop data item description and measurable and accountable scope of work statements for BDAR.
- Establish effective training programs for BDAR at school and unit levels.
 - ▶ Increase hands-on training at schools and unit level training.
 - ▶ Use of excess/turn-in/Property Disposal Office vehicles for BDR training at unit level should be considered.
 - ▶ Develop interactive video courses for BDR training.
 - ▶ Incorporate BDAR into ARTEPS, NTC, and soldiers qualification tests.
 - ▶ Include BDAR as IG inspection items.

- ▶ Use Regional Training Centers for BDAR training.
- ▶ Form specifically trained BDAR teams from the reserve component to augment active component units in a crisis.
- Follow through on policy decision on approving BDAR fixes in peacetime.
 - ▶ Current forbidding warnings against BDAR in peacetime are self-defeating.
 - ▶ Some short-term readiness deficiencies may result when BDAR repairs are used in peacetime, but readiness reporting system must make allowance for this.
- Approve and/or fund BDAR spares for ASL and WRS.
 - ▶ BDAR, without the requisite spare parts, will only have limited impact in wartime.
 - ▶ In sustained combat, a cannibalization policy will not yield nearly the increase in operational weapon systems that sparing for BDAR will.
- HQDA should take an aggressive role in managing and coordinating all aspects of BDAR program: policy, doctrine, R&D, training, funding, spares, kits, TMs, live-fire test, and manpower.
 - ▶ Program is too diverse to be managed at lower levels.
 - ▶ Strong DA advocacy is needed to obtain the resources needed for an effective BDAR program.

APPENDIX C

SUGGESTED CHANGES TO DoD DIRECTIVES AND INSTRUCTIONS

SUGGESTED CHANGES TO DoD DIRECTIVES AND DoD INSTRUCTIONS

OVERVIEW

This appendix provides our recommended changes to DoD Directives (DoDD) and Instructions (DoDI). These changes are required to incorporate battle damage repair considerations explicitly into DoD policy. The specific changes appear in bold italics.

Recommended Changes to DoDD 5000.1
Major and Non-Major Defense Acquisition Programs
Dated 1 September 1987

- Paragraph D. POLICY: subparagraph 9. e, change to read:
"Logistic supportability requirements, in the form of readiness goals, **battle damage repairability** goals, and related design requirements"

Recommended Changes to DoDI 5000.2
Defense Acquisition Program Procedures
Dated 1 September 1987

- Paragraph C. DEFINITIONS: subparagraph 4, Operational Suitability, change to read:

"The degree . . . reliability, ***battle damage repairability***, wartime usage rates"
- Paragraph D. MILESTONE DESCRIPTIONS.
 - ▶ Subparagraph 4.b, change to read:

". . . (6) reliability, maintainability, ***battle damage repairability***, and plans for"
 - ▶ Subparagraph 5.b, change to read:

"Primary considerations . . . are: 1) logistics readiness and sustainability (***including battle damage repair***) in peacetime and wartime"
- Paragraph E. PROCEDURES: subparagraph 4.d, Component Staff Briefings, change to read:

"In support of this, component staff briefings . . . 5) on readiness and support planning to include reliability, maintainability, and ***battle damage repair*** progress to the Director, Weapons Support Improvement Group (DWSIG)"
- Enclosure 4. SYSTEM CONCEPT PAPER (SCP) AND DECISION COORDINATING PAPER (DCP) FORMATS.
 - ▶ Paragraph 8, Description of Selected Alternative, change to read:

"Discuss readiness (***including battle damage repair capability***); sustainability"
 - ▶ Attachment 2. ANNEX B: PROGRAM GOALS AND THRESHOLDS, change to read:

"READINESS/SUPPORTABILITY⁴

Operational⁵

Maintainability

Battle Damage Repairability

Operational Availability”

Recommended Changes to DoDD 5000.39
*Acquisition and Management of Integrated Logistic Support
for Systems and Equipment*
Dated 17 November 1983

- Paragraph D. POLICY: change first sentence to read:
"System readiness *prior to and during combat* is a primary objective of the acquisition process."
- Subparagraph E.1.d, add new entry between (5) and (6):
"() *A funded battle damage repair program to ensure that technologies, techniques, and support items are available to execute Service repair doctrine.*"
- Subparagraph E.1.g, change to read:
"Starting with concept exploration, . . . that best meet readiness, *battle damage repair*, and support cost objectives in fielded systems."
- Subparagraph E.2.a. (1), change to read:
"System operational, maintenance, *and battle damage repair* concepts . . ."
- Subparagraph E.2.b, change first sentence to read:
"Support resource decisions shall be based on system readiness objectives, initial and mature R&M values, *expected battle damage repairability*, and demonstrated field experience on similar programs . . ."
- Subparagraph E.4.b, change first sentence to read:
"Maintain reporting systems and data bases for maintenance data, supply data, deployment, readiness and utilization data, *battle damage repair test and exercise data*, and support . . ."
- Subparagraph F.4.b, change to read:
"Ensure that mission area analyses include support resource (*including battle damage repair*) needs and capabilities."

- Enclosure 2. DEFINITIONS: change the definitions to read as follows:

- ▶ Design Interface –

"The relationship of logistics-related design parameters, such as R&M *and battle damage repairability*, to readiness and support resource requirements"

- ▶ Supportability –

"The degree . . . wartime utilization requirements (*including battle damage repair*)."

- ▶ System Readiness Objective –

". . . System readiness measures take explicit account of the effects of system design R&M, the characteristics and performance of the support system, the quantity and location of support resources, *and the repair of battle damage*"

- ▶ Weapon Support and Logistics R&D –

"Technology programs . . . maintenance of weapon systems, *improved battle damage repair capability*, and improved logistics infrastructure elements."

- Enclosure 3. SUPPORT CONSIDERATIONS IN THE ACQUISITION PROCESS:

- ▶ Paragraph 2. Activities Accomplished by Milestone I:

- Subparagraph h., change to begin:

"Logistics, R&M, and *battle damage repair* parameters"

- Subparagraph m. (1), change to read:

". . . (including unit and strategic mobility *and battle damage repair*)"

- ▶ Paragraph 3. Activities Accomplished by Milestone II:

- Subparagraph b., change to begin:

"A consistent set of objectives and thresholds for readiness, R&M (including built-in test, of applicable), *battle damage repair*, and other logistics parameters"

► Paragraph 4. Activities Accomplished by Milestone III:

- Subparagraph a., change to begin:

"R&M *and battle damage repair testing* have been acceptable"

- Subparagraph b., change to read:

"Parameters . . . based on realistic estimates of demand rates, system utilization, and *battle damage.*"

Recommended Changes to DoDD 3005.5
Criteria for Selected of Items for War Reserves
Dated 4 December 1974

- Paragraph III. B. 3. POLICY: add

"These items will restore combat capability to failed andlor damaged weapon systems."

Recommended Changes to DoDI 4140.47
Secondary Item War Reserve Requirements Development
Dated 24 February 1984

- Paragraph E.2.b. PROCEDURES – Identification of Appropriate Item Data: add () between (1) and (2)

"() Battle damage rates based on typical mission profiles, threat, weapon characteristics, and vulnerability test results."

- Paragraph E.3.b. PROCEDURES – Overall War Materiel Requirements (WMRs) Considerations: add

"... It shall be based on the force structure, level of activity, and expected battle damage applicable to each monthly support period increment"

- Paragraph E.5. PROCEDURES – Wartime Consumption: add at the beginning

"In calculating the WMR, wartime consumption, failure, and battle damage rates shall be developed"

- Enclosure 2, paragraph C.1. ADDITIONAL COMPUTATIONAL GUIDANCE – Development of Consumption Data: change

"The establishment of valid wartime consumption, failure, and/or battle damage rates are the key elements in the development of justifiable war reserve requirements."

- Paragraph b.: add

"For certain war reserve items (e.g., battle damage repair items), peacetime demand ..."

Sources such as like-item usage, engineering estimates, survivability analysis results, live fire test results, previous or simulated wartime experience"

APPENDIX D

RECOMMENDED DEFENSE PROGRAM GUIDANCE

RECOMMENDED DEFENSE PROGRAM GUIDANCE

This appendix provides our specific recommendations for inclusion in the Defense Guidance (DG).

- DG Recommendation 1: In the "Force Readiness" section under "GENERAL READINESS – Wartime Support Capability," add the following midterm objective:

(U) The Services will develop and implement concepts, doctrine, and plans for repairing battle damaged weapon systems in the theaters of operation and, by FY97, deploy a combat damage repair capability to support combat critical equipment and systems. The POMs will include milestone plans to show how each Service will achieve a viable combat damage repair capability. The following elements will be included:

a. (U) A program to procure war reserve stocks of spare parts to support wartime battle damage repair. This will include the development of a methodology for estimating wartime repair parts requirements that integrates battle damage and reliability failure demands.

b. (U) Battle damage repair training programs that provide the required high levels of technical and engineering skills at the repair site during wartime. These programs should incorporate results from live fire tests.

c. (U) Readiness evaluation programs that include an evaluation of a unit's capability to accomplish combat damage repairs.

d. (U) A program to procure essential special repair tools and kits.

e. (U) The preparation and distribution of the necessary damage repair technical publications on all identified weapon systems.

f. (U) Logistics support force structure adjustments and overseas capability, as required, by combat damage repair doctrine.

- DG Recommendation 2: Expand the "Force Modernization" section to include the need to design and develop weapon systems to be combat repairable. This theme should be incorporated throughout this section. We recommend specific guidance to "accommodate rapid field repair of combat damage in design" be included in the survivability/repairability paragraphs.

- DG Recommendation 3: Expand the "Science and Technology" section to address battle damage repair explicitly. We recommend that a midterm objective be established as follows:

(U) Establish a research and advanced technology program, not later than end FY92, to examine all aspects of rapidly repairing combat damage to new systems and application of new technology to repair existing weapon systems. Specific attention should be given to repair of composite materials.

- DG Recommendation 4. Expand the "Test and Evaluation" section to address battle damage repair explicitly. We recommend that planning guidance should be promulgated to:

Prepare an overall plan that describes the strategy, architecture, planning, and baseline capabilities needed to test and evaluate the combat repairability of critical weapon systems.